RELATIVE USEFULNESS OF GASES OF DIFFERENT HEATING VALUE AND ADJUSTMENTS OF BURNERS FOR CHANGES IN HEATING VALUE AND SPECIFIC GRAVITY.

By Walter M. Berry, I. V. Brumbaugh, J. H. Eiseman, G. F. Moulton, and G. B. Shawn.

ABSTRACT.

In connection with an investigation conducted by the Public Service Commission of Maryland to determine the most economic heating value standard for manufactured gas in the city of Baltimore, the Bureau of Standards conducted an extensive series of laboratory tests to determine primarily: (1) The relative utilization efficiency of gases of different heating value; (2) the extent to which present appliances can be adapted to give good and efficient service with gases of different heating value and composition; and (3) what adjustment in appliances is necessary to give the consumers good and efficient service when different kinds of gases are mixed and there is a variation in the composition, heating value, and the specific gravity of the gas.

The laboratory tests of gases varying in heating value from 300 to 600 B. t. u./ft.³ indicated that *the usefulness for top burner cooking is dependent almost wholly upon the total heating value per cubic foot.*

Some change in size of orifice and air-shutter adjustment of burners is necessary to secure the best service when a material change is made in heating value. Most existing burners can be readily adjusted to give good service with heating values as low as 450 B. t. u./ft.³ without alterations of the burners.

Uniformity in heating value, specific gravity, and pressure are essential for the very best service, yet it is practicable to adjust burners to give satisfactory service in cities where different gases are mixed and there is considerable variation in the heating value or specific gravity.

CONTENTS.

I. INTRODUCTION.

1. PURPOSE OF INVESTIGATION.

Reductions in heating value standards in many of our cities within the past two or three years are claimed to have brought about material savings in the cost of manufacture of gas and lower prices to the consumer than if the former standards had been continued. However, the reductions in standards have not always been brought about without some complaint from the consumers that the service was inferior and the total cost greater with a lower-heating value gas than with a gas of higher-heating value.

The Public Service Commission of Maryland has undertaken to investigate this matter very fully, with a view of determining the most economic and satisfactory heating-value standard for the city of Baltimore. In connection with this investigation the commission requested the Bureau of Standards to make laboratory tests to determine the relative efficiency of gases of different heating value and the adaptability of existing appliances for gases differing in heating value and composition.

While the effort was made to have the tests of the relative efficiency of gases of different heating value as practical as possible, it should be appreciated that it is exceedingly difficult to obtain

conditions in the laboratory exactly comparable with those of the average consumer's home. Waste of gas is naturally eliminated in laboratory tests. A definite size of cooking vessel must be used in order to obtain comparable results which have any value. The utensils are clean and in good condition, as is also the stove. Finally, the tests are necessarily limited to the heating of water on top burners; and while this gives an exceedingly valuable indication, it is not necessarily a conclusive proof of the relative quantities of gas of different qualities which will be used by the con-consumers. In fact, the actual data on change of consumption of gas where change in calorific value has been made do not give results agreeing exactly with conclusions which might be drawn from laboratory tests. Due weight should be given to this practical data in drawing any final conclusions.

The question of the relative utilization efficiency of gases of different heating values has been under consideration for several years, both in England and in this country. Exhaustive laboratory tests have been conducted on this subject by the Gas Investigation Committee of the British Institution of Gas Engineers and the Joint Committee on Efficiency and Economy of Gas of the California Railroad Commission.[1] Although the conclusions from the previous laboratory tests have been generally in agreement, it was thought highly desirable to duplicate some of the tests with the gases available in Baltimore and establish carefully the conditions under which the appliances would give the maximum practical efficiency with each kind of gas.

The gas engineering section of the Bureau of Standards has been conducting tests of manufactured and natural gases for several years, and since it had a trained personnel and special testing equipment for studying the combustion of gases, it undertook to make the required laboratory tests, which form one part of the commission's investigation.

In this report the bureau gives the results of tests which show the relative efficiency of utilization of gases of different heating values and composition. The results show also the pressure required to operate the burners, and how appliances can be adapted and adjusted to give satisfactory service with gases of different heating value and specific gravity. The data showing how to adjust appliances to give good service where the relative

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[1] Report of the research subcommittee of the gas investigation committee of Institution of Gas Engineers (England), Gas Journal, Oct. 29, 1918; Nov. 5, 1918. Progress report of Joint Committee on Efficiency and Economy of Gas of the Railroad Commission of the State of California, Gas Age-Record, Nov. 12, 1921; Nov. 19, 1921.

proportions of coal or coke-oven gas and water gas vary should have considerable practical value in many localities.

Baltimore is supplied at the present time with gas having a heating value of 500 B. t. u./ft.³. A portion of the gas is coke-oven gas, purchased by the Consolidated Gas, Electric Light & Power Co. from the Sparrows Point plant of the Bethlehem Steel Co. The latter company is a commercial concern not subject to commission regulation and sells its gas merely as a by-product. The remainder of the supply is water gas, manufactured at the Spring Gardens plant of the Consolidated Gas, Electric Light & Power Co. The standard of heating value in Baltimore was reduced to 500 B. t. u. in June, 1920, in order to allow the economical distribution of the coke-oven gas, which has normally a heating value of about 500 B. t. u.

2. SCOPE OF THE LABORATORY TESTS.

The laboratory work in Baltimore was divided into three parts, as follows:

(1) The first series consisted of numerous practical efficiency tests made with 10 different kinds of gas when the gas rate and air shutter were adjusted in each case to produce a good flame. These tests were made on two different ranges and the results show the efficiency, the time required, and cubic feet of gas used to bring 2 quarts of water to boiling from an initial temperature of 80° F.

In order to gather information on the composition of the combustible mixture within the burner at the condition of good adjustment for each gas, the burner was removed from the range after each adjustment and connected to special apparatus which had been developed for that purpose.

The condition at which the flash back and the blowing from the ports occur with each kind of gas represents a rather definite relation between velocity through the ports and composition of the air-gas mixture. The yellow tips also occur at rather definite mixtures of gas and air. These conditions were also determined with the above-mentioned apparatus.

(2) The principal object of the second series of tests was to establish more definitely the workable limits of operation of burners with gases of different heating value and specific gravity. This part of the laboratory schedule consisted of a series of tests made with water gas of 400, 500, and 600 B. t. u. and coal gas of 525 B. t. u. With each kind of water gas the burner was operated at three rates of consumption, namely, 7,000, 9,000, and 11,000

B. t. u./hr.   The cone and flame heights and the limits of adjust-
ment within which the burner could be satisfactorily operated
were observed.

This matter of correct appliance adjustment is of considerable
importance in cities where coke-oven or coal gas and water gas
are mixed.   As a result of the daily and seasonal variations in
demand it is difficult to maintain the ratio of the two gases con-
stant and, therefore, there may be considerable variation in the
specific gravity of the gas with a resulting change in air entrain-
ment and variation in flame characteristics.

(3) The third part of the investigation consisted of a series of
tests with water gas of 500 and 600 B. t. u./ft.[3] to determine the
position of vessel relative to the gas burner that would give the
highest thermal efficiency without forming dangerous quantities of
carbon monoxide.   In these tests the utensil was placed at dis-
tances of 1½, 1¼, 1, and ¾ inches from the burner.   Tests were
made with three gas rates, 7,000, 9,000, and 11,000 B. t. u./hr.

The efficiency that can be secured in top-burner cooking will
depend upon the distance of burner from the utensil and upon the
flame characteristics.   Good flame contact is essential for rapid
heating (the consumer's idea of good service) and high efficiency,
but the smothering of the flame is dangerous on account of the
production of carbon monoxide.   At each rate and at each posi-
tion of vessel the flame was adjusted for three different condi-
tions, namely, a hard flame, a medium flame, and a soft flame.
A large number of carbon-monoxide determinations were made
under each condition of operation with the ordinary star and disk
types of burners.   The results of the tests show how the pro-
duction of carbon monoxide is affected by a change in the dis-
tance between the burner and the vessel, variation in rate of
gas consumption, or use of different types of burners.

II. PREPARATION OF GAS SAMPLES OF DIFFERENT HEATING VALUES.

In order that a sufficient volume of gas of a constant heating
value be available for a series of tests a gas holder with a capacity
of approximately 300 feet[3] was secured.   For purification pur-
poses the gas before entering the holder was passed through the
tar scrubber and purifier shown in Figure 1.   The tar scrubber
was 2½ feet in diameter and 12 feet high and was filled with dry
wood shavings.   This scrubber completely removed all the tar
in the gas.   The purifier, 2½ feet in diameter and 3 feet high, was
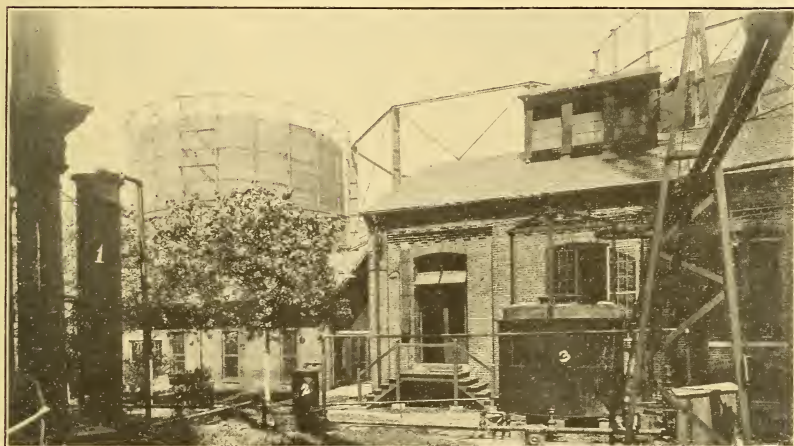
FIG. 1.—*View of tar scrubber (1), purifier (2), and gas holder (3) used in these tests.*

filled with iron oxide and wood shavings, which completely removed all traces of hydrogen sulphide.

The city gas used in our tests was piped to our holder direct from the Consolidated Gas, Electric Light & Power Co.'s city distribution line. This gas contained approximately one-third coke-oven gas and two-thirds water gas and the heating value was approximately 500 B. t. u./ft.^{3}

The coke-oven gas was received from the Sparrows Point plant of the Bethlehem Steel Co. The gas as received at Baltimore was free of tar but not of hydrogen sulphide, and it was necessary to purify it before entering our holder. The coke-oven gas used in these tests had a heating value of about 450 B. t. u./ft.^{3}

Coal gas, a gas similar to coke-oven gas but usually of somewhat higher heating value, was secured from the Philadelphia Gas Works, since there were no facilities for its manufacture in Baltimore. It was compressed and shipped in high-pressure cylinders. The heating value of the gas was about 525 B. t. u./ft.^{3} when released into our holder. The gas as received was free of tar and hydrogen sulphide.

All of the water gas was manufactured at the Spring Gardens plant. A connection was made to the outlet of the wash box of a generator set and from there the gas was piped about 400 feet through a 4-inch line to a tar scrubber, purifier, and finally into the gas holder. Gases of different heating values were made by varying the quantity of gas oil sprayed into the carbureter.

III. DESCRIPTION OF APPARATUS AND METHODS USED IN TESTING.

1. TYPES OF BURNERS AND RANGES USED IN TESTING.

In the tests of this report three different designs of top burners were used and are shown in Figure 2. These burners are known as regular front top burners and are often designated as "standard" size (about 4 inches in diameter) to differentiate them from other sizes. Gas ranges of average size are generally equipped with three regular, one giant, and one simmering burner.

Burner No. 1 was selected because it is the most extensively used in Baltimore and also represents the "star" type of burner.

Burner No. 2 which is of the "disk" type, was selected because it was desired to test a burner of an old design, many of which are still in service in Baltimore.

Burner No. 3 was used only in the study of the effect on efficiency with a change of distance of utensil from burner. It is one of the

later designs of the "disk" type of burner and is much used in New York City.

The ranges which were used to determine the efficiency of gases of different heating values are shown in Figures 3 and 4, respectively. They were obtained from consumers' premises where new ranges had been purchased.

2. KIND OF UTENSIL USED.

In this investigation no attempt has been made to study the effect on the efficiency if the size or shape of the utensil, relative to the size of the burner, is varied, nor the probable change in efficiency that would result from the use of utensils made from various materials or those made with different weights of material. A light-weight aluminum utensil was selected such as that shown in Figure 6. It is model No. 44–A made by the Aladdin Aluminum Co. The maximum diameter is 8.1 inches and the capacity is 4 quarts. This size of utensil was used in all the efficiency tests here reported.

3. HOW THE RELATIVE EFFICIENCY OF THE GASES WAS DETERMINED.

In past investigations of this bureau, tests of efficiency of heating were made by heating a given weight of water through a temperature rise of 100° F. Before adopting the method used in this investigation, tests were made to ascertain the difference in efficiency, if any, between heating water from tap-water temperature through 100 ° F. rise or from tap-water temperature to boiling. The effect of stirring the water during heating was also determined. The results were as follows: Two quarts of water heated to boiling, *stirred*, gave 36.8 per cent efficiency; 2 quarts of water heated to boiling, *not stirred*, gave 36.5 per cent efficiency; and 2 quarts of water heated through 100° F. gave 37.5 per cent efficiency.

It is apparent from the above that stirring the water does not appreciably alter the efficiency, nor is the efficiency of heat absorption much different whether the water is heated over a greater or less difference in temperature.

It is also of interest to know whether the rate of heat absorption is constant from the time the utensil is placed over the burner until boiling begins. The curves of Figure 5 show that the rate of heat absorption is constant and depends directly upon the rate of supply of heat.

To make the tests here reported the following method was selected. Two quarts (4.17 pounds) of water were heated from
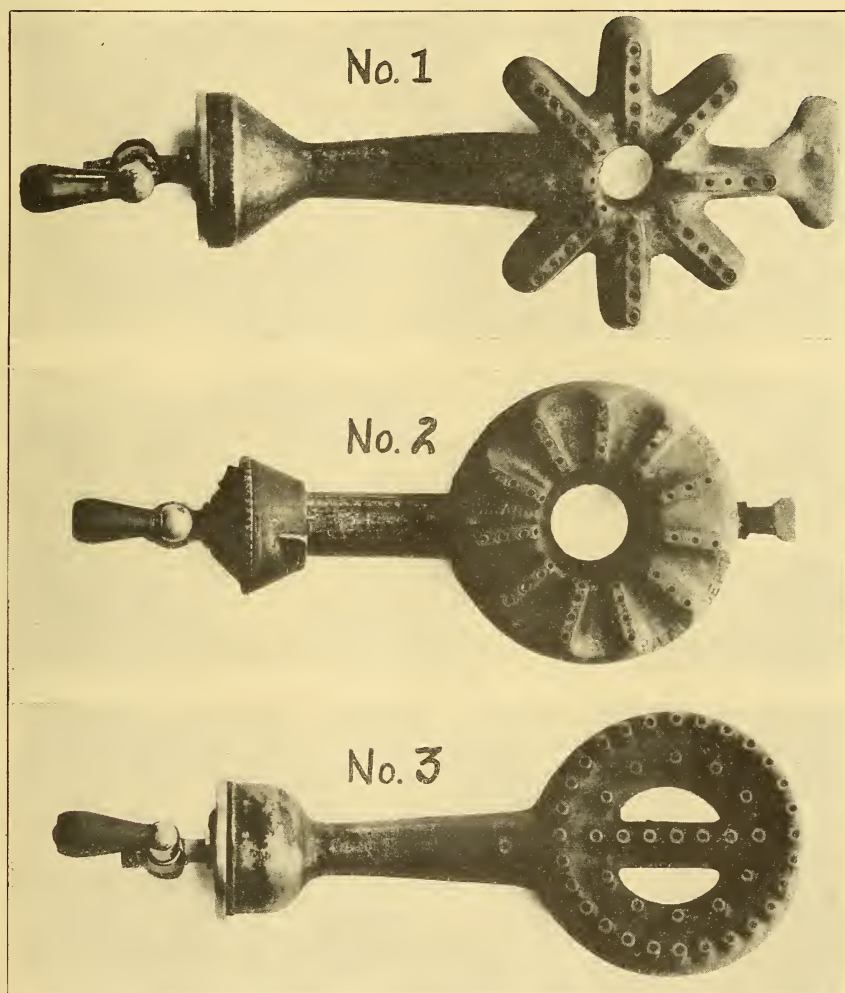
FIG. 2.—*Top view of burners used in the tests.*

Burner No. 1 "star" type, burner No. 2 old "disk" type, and burner No. 3 new "disk" type.
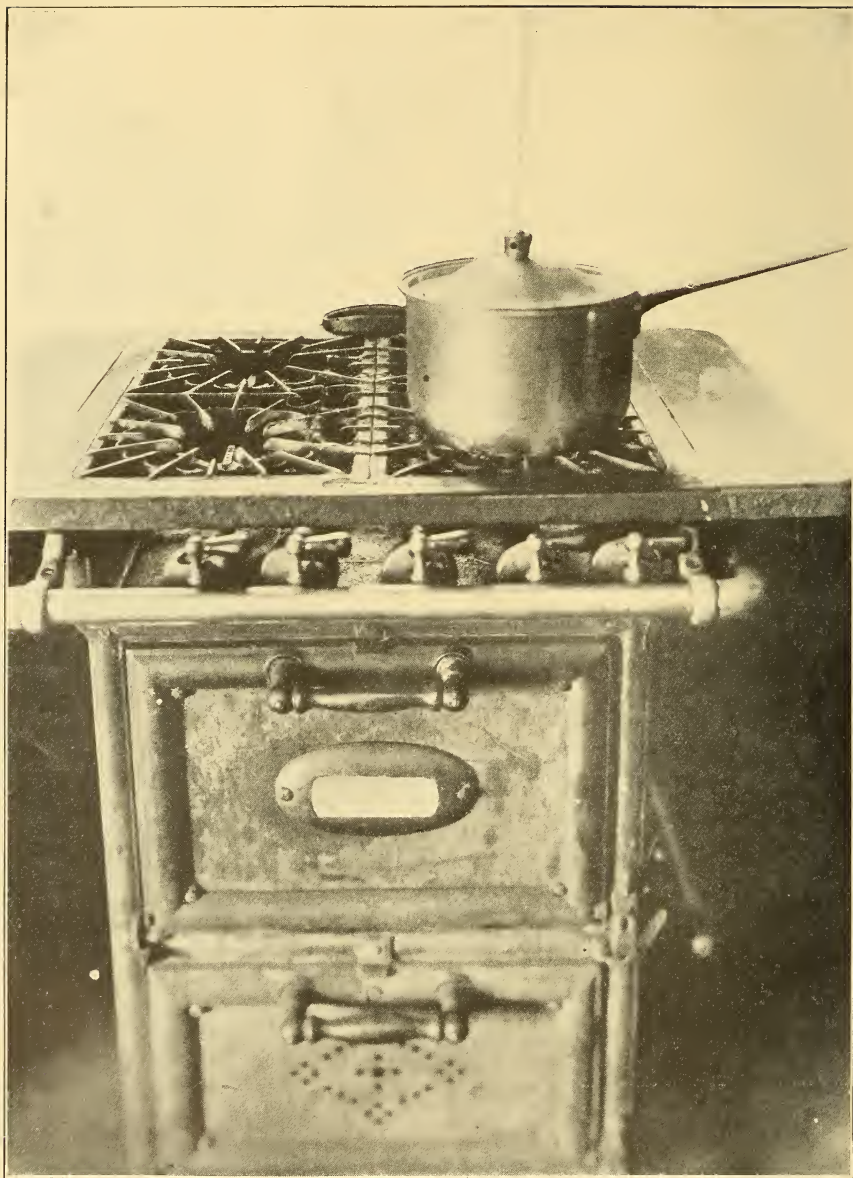
FIG. 3.—*Gas range equipped with burner No. 1 showing utensil used in efficiency tests.*

tap-water temperature to boiling. The initial temperature was very carefully noted just before the utensil was placed over the burner. At the instant the utensil was placed over the burner the gas meter reading was taken. The observer who placed the utensil over the burner watched the water temperature until it just reached the boiling point when he signaled to the person who read the gas meter.
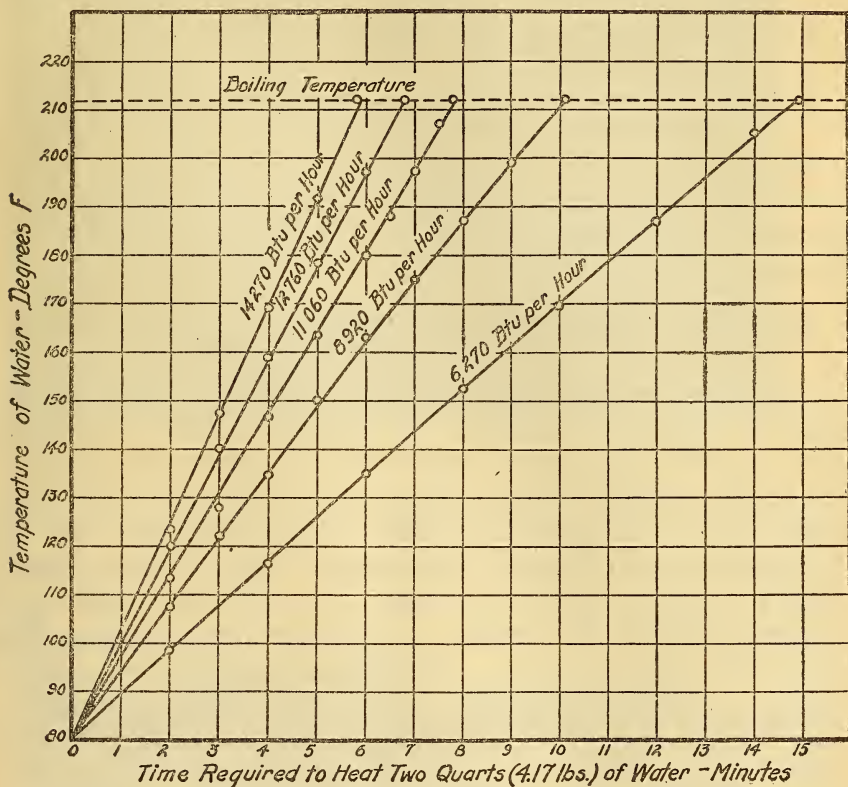
FIG. 5.—*Curves showing the variation of rate of heating water with different B. t. u. rates.*

Burner No. 1 was used to make the tests and was placed 1⅜ inches from the utensil shown in Fig. 3.

During a test the gas temperature, the pressure of the gas in the meter, and the barometric pressure were noted. The difference between the meter readings at the time the utensil was placed over the burner and at the time the water reached 212° F. gave the uncorrected volume in cubic feet of gas consumed. This volume was then corrected to the standard barometric condition of 30 inches of mercury pressure at 60° F. The efficiency was calculated on the basis of the quantity of heat absorbed by the water relative to the total quantity of heat contained in the gas con-

sumed. No allowance was made for the heat absorbed by the utensil. The efficiency may, therefore, be computed from the simple equation,

$$\text{Efficiency} = \frac{W \times T}{\text{B. t. u. per cubic foot} \times V \times F}$$

where

    W = weight of water, 4.17 pounds (2 quarts) in the case of the tests of this report.

    T = temperature rise of water, degrees F.

    V = uncorrected volume of gas consumed.

    F = correction factor which reduces uncorrected volume to 30 inches of mercury pressure at 60° F.

The efficiency values shown in this paper are an average of two tests at each position. By making two tests errors in reading the gas meter or the thermometer or in weighing the water would be detected.

4. APPARATUS AND METHOD USED TO TEST THE OPERATION OF BURNERS WITH DIFFERENT GASES.

The set-up used in making the tests of operation of burners is shown in Figure 6. There are two meters, a 5-light wet meter used to meter the gas and a 10-light wet meter for metering the air. After being metered, the gas passes by an opening to a gas bag which serves to eliminate any slight pressure irregularity due to the operation of the meter mechanism. The gas then passes through a pressure regulator by which it is possible to regulate the pressure desired at the orifice. A regulator and a gas bag are placed before the air meter. The regulator reduces the air-line pressure, while the gas bag removes some of the fluctuations caused by the air compressor. Between the air meter and the connection to the wooden box is another gas bag which removes the remaining fluctuations in the air line. After this gas bag is a valve which is used to regulate the flow of air. The mixer portion of the gas burner is sealed in the end of the box opposite the point at which the gas line enters. The gas-line pressure is taken at a point just back of the orifice and is connected to a pressure gauge outside of the box. The air line is joined to the box directly above the point at which the gas line enters. A baffle is placed in front of the air inlet in order to reduce the velocity of the air as it enters the box. The box has a removable lid and is made air-tight. On one side of the box a hole 6 inches square is cut, and a piece of shellacked paper is glued over the opening to form an explosion
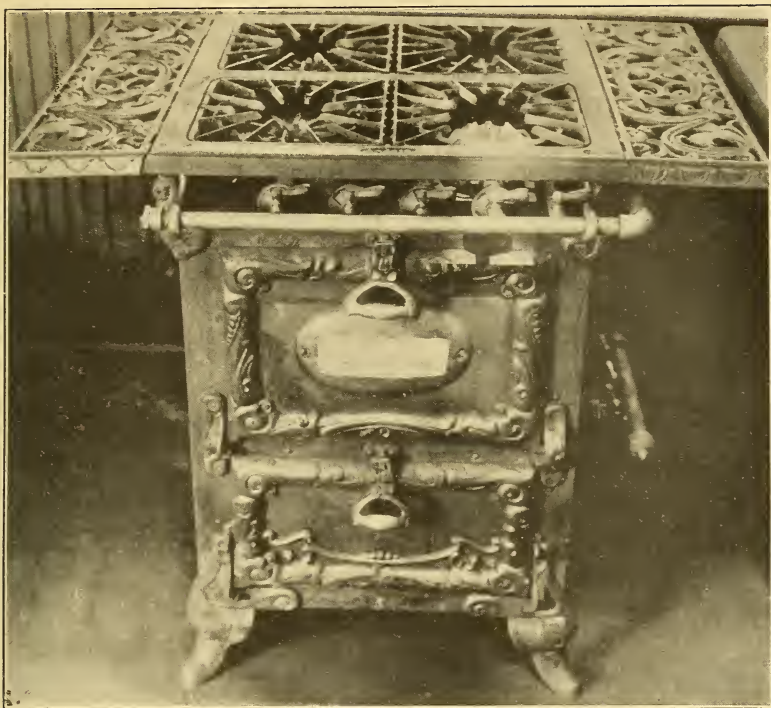
FIG. 4.—*Gas range equipped with burner No. 2 used in efficiency tests.*
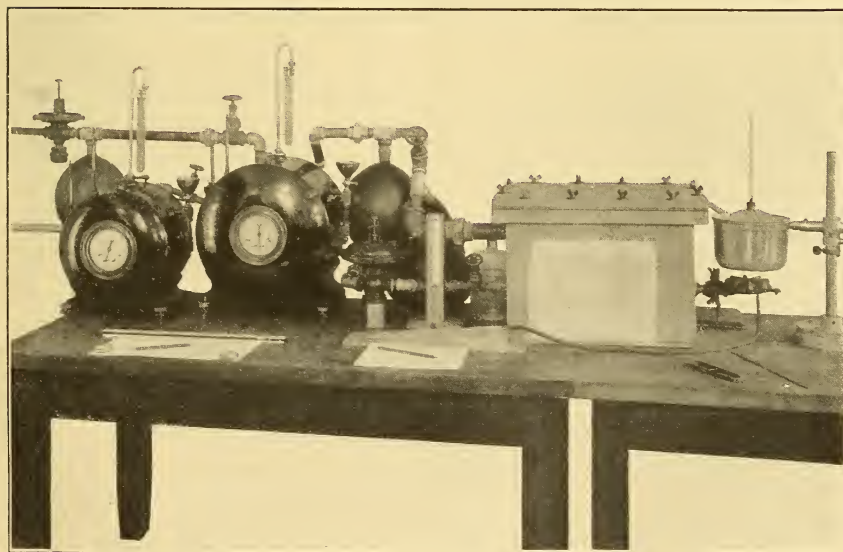
FIG. 6.—*Apparatus used to determine the primary air that was injected into a burner at any condition of operation.*
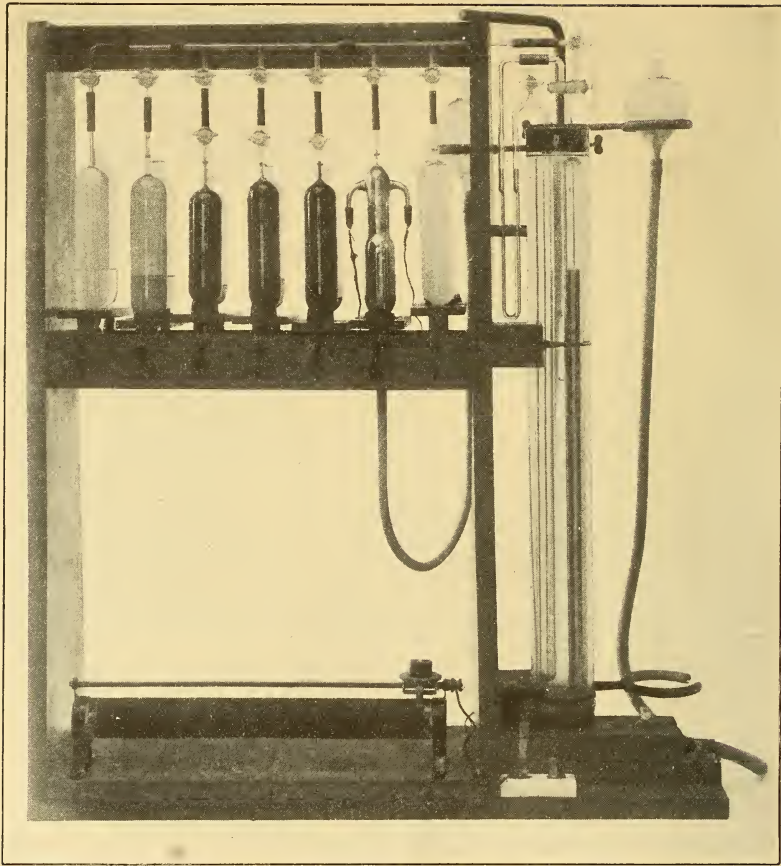
FIG. 7.—*Orsat gas analysis apparatus used to determine the constituents of the gases.*
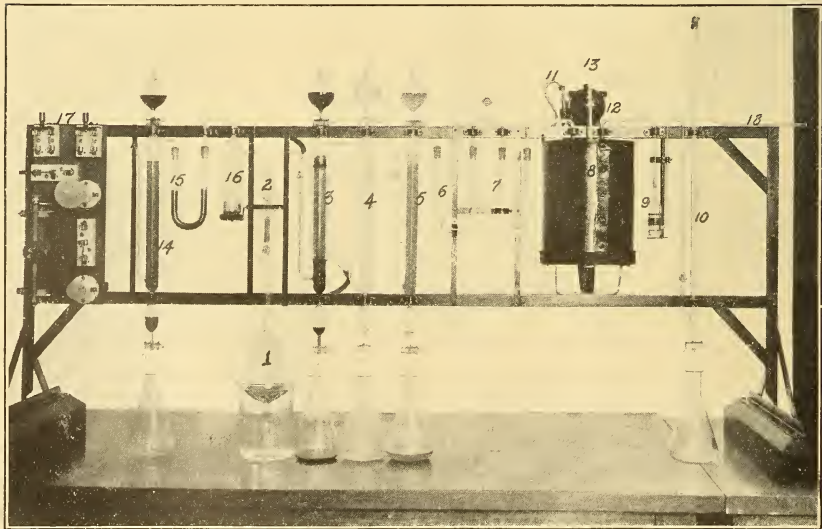
FIG. 8.—*Apparatus used for analyzing products of combustion for carbon monoxide.*

head. A very sensitive slope U gauge is constructed to measure the extremely minute pressures that occur in the burner. Xylene is used in this gauge because it does not adhere to the wall of the U tube.

With the apparatus which has been described it is possible to produce in the burner any desired air-gas mixture. Because it is impossible to operate a burner above an air-gas ratio that will cause the flames to leave the ports or flash back into the burner, and it is impracticable to operate the burner with a primary air-gas ratio which produces a yellow flame, these conditions were determined when testing a burner. To make the tests, the lid was placed on the box, and air was metered into the box at rates which produced these conditions for different gas rates. The ratio of the volume of air to the volume of gas that entered the burner was readily calulated by timing the two meters.

The amount of air which was injected into the burner at different pressures for any definite air-shutter adjustment was also determined. This was accomplished by first operating the burner normally, with the top of the box removed, and observing carefully the orifice pressure and the pressure in the burner as indicated on the very sensitive slope U gauge. The lid was then placed on the box and the air passed through a meter into the box at a rate which exactly duplicated the previous condition of pressure within the burner. It is evident that since the gas rate in each case was the same, the volume of air injected into the burner in each case must have been the same. The primary air-gas ratio for gas pressures of 0.25, 0.5, 1, 2, 3, 4, and 5 inches was thus obtained.

Before beginning a test the gas was lighted long enough for the burner to be heated to its normal temperature. All tests herein reported, therefore, were obtained with the "burner hot."

5. METHOD OF GAS ANALYSIS.

An Orsat type of gas analysis apparatus was used for analyzing the various gases used in the tests, also for the determination of the amount of carbon dioxide and oxygen in the products of combustion as sampled above the burner. The apparatus as used is shown in Figure 7.

Mercury was used as the confining liquid in the gas measuring burette. By means of the method of compensation all volume measurements were made at a temperature and pressure that are constant for any analysis. The absorbable constituents were

removed by using the following reagents in the several pipettes: (1) Sodium hydroxide solution for the removal of carbon dioxide (CO_2); (2) fuming sulphuric acid for the removal of the illuminants; (3) alkaline pyrogallol solution for the removal of oxygen (O_2); and (4) acid cuprous chloride for the removal of carbon monoxide (CO).

The amounts of hydrogen (H_2) and methane (CH_4) were determined by the slow combustion method. The amount of ethane (C_2H_6) present in the gases was not determined separately, but the amount being small the error introduced by including it with the percentages of hydrogen and methane present may be ignored.

6. APPARATUS AND METHOD USED FOR ANALYZING PRODUCTS OF COMBUSTION FOR CARBON MONOXIDE.

The amount of carbon monoxide (CO) present in the products of combustion is important as a criterion of the completeness of combustion and of the safe and efficient operation of a burner. A careful analysis of the products of combustion for carbon monoxide was made using the apparatus shown in Figure 8. The general arrangement of apparatus is practically the same as that used by Larson and White, who did considerable work on the quantitative determination of carbon monoxide while in the Chemical Warfare Service. The method is based on the reaction of carbon monoxide (CO) and iodine pentoxide (I_2O_5), which results in the liberation of iodine and the formation of carbon dioxide ($I_2O_5 + 5CO = I_2 + 5CO_2$). The liberated iodine is absorbed in potassium iodide (10 per cent solution) and the amount is determined by titration with carefully standardized sodium thiosulphate ($Na_2S_2O_3$). Since the amount of liberated iodine and the volume of sample passed through the apparatus is known, the amount of carbon monoxide in the products of combustion as sampled can be calculated.

In order to get a result that is comparable with that for any other burner, the products of combustion are analyzed for content of carbon dioxide and oxygen by means of the Orsat apparatus. The amount of oxygen in the sample is directly related to the air present, namely, where $x =$ amount of oxygen in the sample, and since normal air contains 20.93 per cent oxygen by volume, then

$$\frac{20.93 - x}{20.93} = \text{per cent of products of combustion free from air.}$$

Using this factor we can calculate the per cent of carbon monoxide and carbon dioxide on the air-free basis. The calculation of the

carbon monoxide produced in cubic feet per hour is made as follows:

Let a = per cent of CO (air-free basis).
b = per cent of CO_2 (air-free basis).
C = CO_2 produced by combustion of 1 foot^3 of gas.
R = rate at which gas is burned in cubic feet per hour

then

$$\frac{a}{a+b} \times C \times R = \text{cubic feet of carbon monoxide produced per hour.}$$

Referring to Figure 8, the path of travel of the sample of the products of combustion will be traced as the sample is drawn through the apparatus by suction, connection for which is made at 18. The sample of the products of combustion is contained in the sampling tube (1) and is displaced by means of water. As the water rises in the sampling tube (1) and displaces the sample it ultimately acts on the float valve (2) which automatically cuts off the flow of water and allows the purging with air to begin. The sample passes through absorption towers filled with glass beads containing, respectively, chromic acid (3), sodium hydroxide (4), and concentrated sulphuric acid (5). The absorption tower containing chromic acid is heated to approximately 212° F by means of a steam jacket. The hot chromic acid will remove any illuminants, should there be any present; while the sodium hydroxide will remove the carbon dioxide (CO_2) and the sulphuric acid will absorb most of the moisture. The U-tube (6) contains stick sodium hydroxide (NaOH) and acts as a guard tube for the absorption tower of sulphuric acid and it also will remove any trace of carbon dioxide that might still be in the sample. The next U-tube (7) contains phosphorous pentoxide (P_2O_5) where the last trace of moisture is removed. The unit marked "8" is an oil bath in which is mounted a U-tube containing alternate layers of iodine pentoxide and glass wool. The bath is heated by an electric immersion type heater (11) to a temperature of 310° F. (155° C.) and a uniform temperature is maintained by means of a stirring motor (12). The liberated iodine is absorbed in a potassium-iodide solution contained in a Gomberg bulb (9). The Gomberg absorption bulb is attached by ground-glass joints so that it can be easily removed and the iodine solution rinsed into a flask for titration with standardized sodium-thiosulphate solution. The air used in purging passes through an absorption tower containing concentrated sulphuric acid (14), and a U-tube filled with

activated charcoal for the removal of any carbon monoxide that might be in the room atmosphere. The mercury trap (16) acts as a seal when the sample is drawn into the apparatus and also prevents dust in the charcoal from being carried over by the air used in purging. The electric heater and stirring motor are controlled by means of a rheostat and lamps mounted on the switchboard (17) at the extreme left.

The method used in sampling the products of combustion is fully described in "Carbon monoxide in the products of combustion fron natural gas burners," by I. V. Brumbaugh and G. W. Jones. Figure 9 shows the apparatus used.
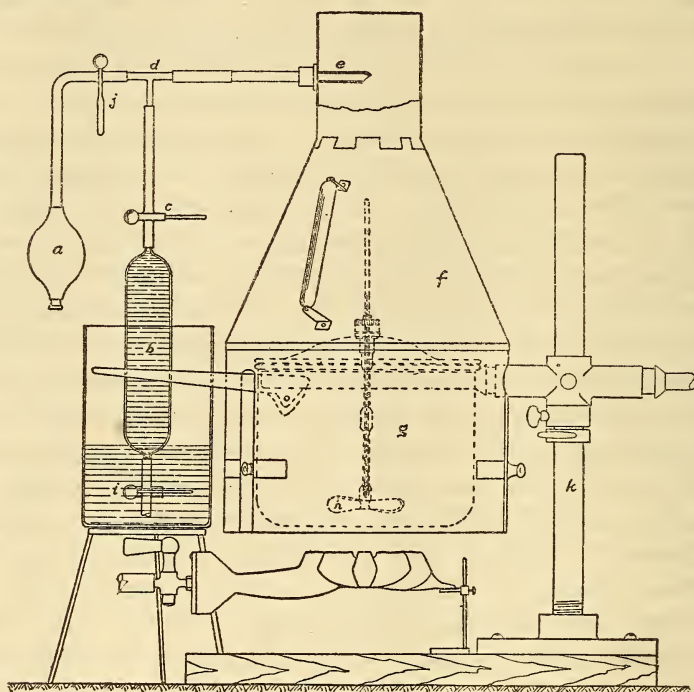
FIG. 9.—*Apparatus used for sampling products of combustion.*

IV. TIME REQUIRED AND CUBIC FEET OF GAS USED TO HEAT 2 QUARTS (4.17 LBS.) OF WATER TO BOILING, CALCULATED EFFICIENCY OF HEATING, AND THE CONDITION OF GOOD ADJUSTMENT FOR TWO TYPES OF BURNERS.

It has been often said that laboratory tests are made with such high degree of accuracy and refinement in adjustment that the application of the results to actual practice is very difficult. Every effort was made in this series of efficiency tests of gases of

10 different heating values to make the condition of test as practical as possible. The tests of each gas were made on each of the ranges shown in Figures 3 and 4. The burners were adjusted in the way that a practical gas fitter would adjust the appliance in a consumer's home.

In Baltimore the pressure of the gas when supplied at the consumers' appliances averages about 3 inches. The initial adjustment of the burners for each kind of gas was made for that pressure. After the careful initial adjustment no other changes were made in the gas orifice or air shutter when the burner was operated at other pressures.

To make a good adjustment the gas-line pressure was first set for 3 inches; then the orifice was so reamed (if necessary) and the air shutter so set that a flame was obtained which was distinctly blue, with a pronounced blue inner cone. The type of flame with good adjustment of gas and primary air might be described as a "normal flame." The flame was neither "hard and stiff" nor "soft and flimsy."

In this connection the reader must bear in mind that when a burner is adjusted for the right kind of flame at a pressure of 3 inches and the pressure is then reduced to 1 inch or increased to 5 inches, *the type of flame is not visibly altered but the rate of flow of gas and, therefore, the size of the flame with each pressure is decidedly different.*

Complaints of poor service are often made when the gas pressure is adequate and the capacity of the service pipe is sufficient, but the orifice on the appliance is too small to deliver the desired amount of gas. On the other hand, complaints arise when the demand for gas is greater than the capacity of the service pipes. It is almost impossible to maintain an absolutely uniform pressure at all times, and tests of efficiency with each kind of gas were made, therefore, when gas was supplied at pressures of 1, 2, 3, 4, and 5 inches. The results obtained are plotted on the curves of the various figures and are marked "efficiency," where efficiency in per cent is plotted as the ordinate with gas-line pressure in inches of water as the abscissa.

The time required to heat the water (2 quarts) from initial temperature to boiling was noted in each case. The time required to heat from 80° F. to boiling was then calculated. These are the time values shown in the tables and are the same as those which have been plotted and are labeled "Time required to heat 2 quarts of water to boiling."

110180°—22——2

From the amount of gas used and the time required for a test the gas rate in cubic feet per hour was determined. The results are shown in the tables and also in the various figures by the curves marked "Rate, cubic feet per hour."

The above procedure was followed and the results plotted in a similar manner with each of 10 different gases.

After the efficiency tests of each kind of gas had been completed, the burner with the same gas cock and orifice was connected to the burner-testing apparatus without changing the adjustment of the air shutter. With this apparatus the amount of primary air injected into the burner by the gas, with the air shutter set for "good adjustment," was determined at pressures ranging from 0.25 inch to 5 inches. These values are shown by the curves marked "Primary air-gas ratio obtained with good adjustment."

If too much primary air is injected into a burner, the flames will blow from the ports or flash back. From previous experience of the bureau in work for commissions and municipalities it may be stated that when operating burners under these conditions the public will complain of "air in the gas," "poor gas," and popping of burners. The burners were operated with each kind of gas under varying gas rates and the amount of air determined which would cause the flames to just leave the ports or to flash back into the burner at each gas rate. The dashed line labeled "flames blow from ports" and "flash back" show at what rate of consumption and ratios of primary air to gas this complaint could occur with the different gases. It will be observed that the curve showing the condition of good adjustment for each kind of gas falls well below the curves for "flash back" and "flames blow from ports."

Since the velocity of combustion varies with the composition of the gas, and the velocity of the mixture through the ports varies with the port area of the burner, the ratios at which the "flash back" and "blow from ports" conditions occur will vary with the kind of gas, the heating value, the rate of consumption, and the type of burner.

If only a certain ratio of air to gas is admitted into the burner with the gas, a yellow-tipped flame will result. The values of the air-gas ratios at which this condition occurs are shown for the different kinds of gases by the curves marked "Yellow tip appears at this ratio." Such a flame will generally blacken the utensil and is likely to liberate poisonous products. The housewife strenuously objects to a flame that blackens utensils.

The amount of air required for the complete combustion of 1 foot^3 of gas is calculated from the analysis of the gas and is indicated by a dashed line marked "Ratio required for complete combustion" on the figures that follow. The average height of the flame and the blue inner cones were measured at the time of each efficiency test. The average height of the flame is very difficult to determine and the values shown in the tables are only approximate. The height of the blue inner cone is very definite and easily measured.

1. TESTS OF "500" B. T. U. CITY GAS (MIXED COKE-OVEN AND WATER GAS).

(a) BURNER NO. 1.

The pressure was set at 3 inches; then the size of the gas orifice and the opening of the air shutter of the burner were adjusted to obtain the type of flame which appliance fitters consider will give the best service. With this adjustment the air shutter was about 20 per cent open. Without changing the burner adjustments, efficiency tests were made at pressures of 1, 2, 3, 4, and 5 inches.

In Table 2 are given the rate of consumption in cubic feet per hour, B. t. u. per cubic foot, B. t. u. delivered per hour, cone and flame height, minutes required to heat 2 quarts of water from 80° F. to boiling, the cubic feet of gas used, and the efficiency obtained at the above five pressures. The values of efficiency, rate of consumption in cubic feet per hour, and the time required to heat 2 quarts (4.17 pounds) of water from 80° F. to boiling are plotted in Figure 10.

The burner, with the same gas cock, orifice, and air-shutter adjustment, was connected to the burner-testing apparatus to determine how much of the air required for combustion entered the burner through the air-shutter opening. The air-injection tests are plotted in Figure 11 and connected by solid lines and labeled "Primary air-gas ratio obtained with good adjustment." Let us consider the case when the burner was operated at a pressure of 3 inches and the gas rate was 22.7 feet^3/hr. The test showed that 52.2 feet^3 of air per hour were injected into the burner. The ratio of primary air to gas was 52.2 divided by 22.7, which equals 2.3. This is the value plotted on the curve and marked "3 in." The other points of the curve show the ratios obtained at other pressures.

From the analysis of city gas given in Table 1 it was computed that the oxygen from 4.26 feet^3 of air is required to completely

burn a cubic foot of the gas. This value is shown by the dashed line of Figure 11 labeled "Ratio required for complete combustion."

Referring again to the rate of consumption at 3 inches pressure, the total air required for complete combusion was $22.7 \times 4.26 = 96.7$ feet^3 of air per hour, or $96.7 - 52.2 = 44.5$ feet^3 of air per hour supplied as secondary air.

It will be noted in Figure 11 that the burner will not flash back under any condition when the gas rate exceeds 6 feet^3/hr. Beyond this rate the flames will leave the port when the air-gas ratio is high enough to make the velocity of the mixture through the ports greater than the velocity of combustion. The ratio at which the flames leave the ports is plotted for varying gas rates in the curve marked "Flames blow from ports" in Figure 11.
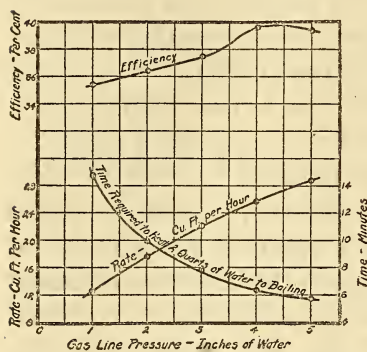
FIG. 10.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with city gas of 492 B. t. u. and burner No. 1.*
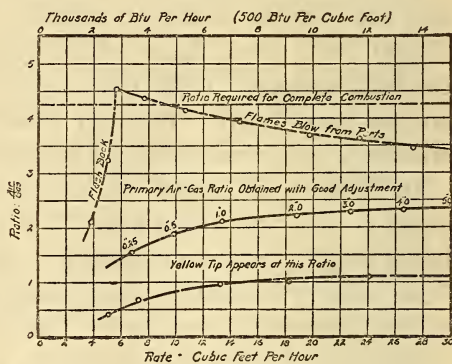
FIG. 11.—*Primary air-gas ratio obtained with city gas of 495 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.628.

The reader will observe in Figure 11 that the air-gas ratio at the good adjustment with any gas rate is well below that at which the "flames blow from ports" or the "flash back" occurs and is well above the ratio at which yellow tips appear at the top of the blue inner cone.

TABLE 1.—Average Analysis of "500" B. t. u. City Gas[1] Used in Tests.

CO_2	per cent..	4.1
Illuminants	do....	6.5
O_2	do....	.8
CO	do....	21.5
CH_4	do....	16.2
H_2	do....	36.6
N_2	do....	14.3
Specific gravity		.619
Noncombustibles	per cent..	19.2

[1] City gas consisted of approximately one-third coke-oven gas and two-thirds water gas.

TABLE 2.—"500" B. t. u. City Gas, 0.618 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	12.74	491	6,255	0.28	0.70	14.88	3.16	35.5
2	17.95	497	8,920	.38	.94	10.13	3.03	36.5
3	22.48	491	11,040	.44	1.16	7.97	2.98	37.6
4	25.95	491	12,740	.50	1.35	6.52	2.82	39.8
5	29.08	491	14,270	.55	1.45	5.85	2.84	39.6

(b) BURNER NO. 2.

The same orifice that was used with Burner No. 1 to test "500" B. t. u. city gas was connected to Burner No. 2. The air shutter was then completely closed to make the good adjustment. It should be noted that the mixer of Burner No. 2 (see Fig. 2) is a separate casting into which the injecting or mixer tube makes a loose fit, the slot for the set screw of the air shutter is uncovered when the shutter is closed, and the air-shutter cap is not tight

Fig. 12.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with city gas of 492 B. t. u. and burner No. 2.*

Fig. 13.—*Primary air-gas ratio obtained with city gas of 495 B. t. u. and burner No. 2 a the different conditions of operation.*

Specific gravity of gas, 0.628.

against the mixer face. These openings alone allowed a sufficient amount of primary air to enter the burner at the good adjustment.

The efficiency values, etc., are given in Table 3. If one will compare the results of the tests of city gas obtained with Burner No. 2 with those of Burner No. 1, it will be noted that there is no appreciable difference. This is due primarily to the fact that both burners were the same distance from utensil (1⅜ inches) and the

type of flame with each was approximately the same as shown by the cone heights given in Tables 2 and 3. Since the same orifice was used when testing with each burner the same gas rates are obtained at corresponding pressures, and since the efficiency in each case is approximately the same, it follows that there should be no appreciable difference in the time required to heat a given amount of water to boiling at a given pressure. The curves of Figures 10 and 12 verify this since they are almost identical.

The operation tests of Burner No. 2 are shown by Figure 13. The location of the curves are very similar to those of Figure 11, showing the test of Burner No. 1. The curve showing the "primary air-gas ratio obtained with good adjustment" is a little lower than that for Burner No. 1. Those who made the adjustment believed they had exactly duplicated the flame used in the tests of Burner No. 1, but there is some question whether the eye can detect any less variation in the type of flame.

TABLE 3.—"500" B. t. u. City Gas, 0.624 Specific Gravity—Burner No. 3, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.^{3}/hr.	B. t. u./ft.^{3}	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.^{3}	Per cent.
1	11.94	495	5,860	0.31	0.64	15.22	3.03	36.7
2	17.27	492	8,500	.37	.70	10.32	3.00	37.3
3	21.45	492	10,550	.40	.85	8.23	2.98	37.5
4	25.92	492	12,750	.48	1.40	6.98	3.02	37.1
5	29.20	492	14,370	.50	1.50	6.44	3.14	35.5

2. TESTS OF "450" B. T. U. COKE-OVEN GAS.

(a) BURNER NO. 1.

With coke-oven gas it was found that the same orifice and air-shutter adjustment as made for the city gas was correct for good adjustment. The fact that no readjustment was necessary may be accounted for by the increase in the rate of gas consumption (due to the lower specific gravity) compensating for the drop in heating value. In other words, the hourly rate of B. t. u. supplied to the burner changed but little and the momentum of the gas (which governs the primary air injection) remained approximately the same with the result that the appearance of the flame was not visibly altered.

The average analysis of the gas used in this test is given in Table 4. Table 5 and Figures 14 and 15 require no detailed explanation for the reader familiar with the preceding discussion.

The adjustment of the air shutter of Burner No. 1 for the "450" B. t. u. coke-oven gas was such as to give an air opening approximately 20 per cent of the area of the air inlet.
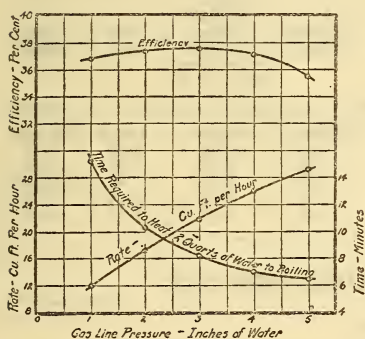

FIG. 14.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with coke-oven gas of 447 B. t. u. and burner No. 1.*
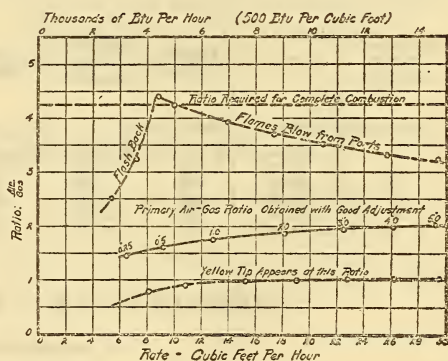

FIG. 15.—*Primary air-gas ratio obtained with coke-oven gas of 447 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.55.

TABLE 4.—Average Analysis of "450" B. t. u. Coke-Oven Gas as Received from Sparrows Point, Md.

CO_2	per cent..	3.2
Illuminants	do....	3.0
O_2	do....	1.0
CO	do....	9.6
CH_4	do....	22.8
H_2	do....	41.5
N_2	do....	18.9
Specific gravity		.54
Noncombustibles	per cent..	23.1

TABLE 5.—"450" B. t. u. Coke-Oven Gas, 0.55 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft./hr.³	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	13.25	447	5,930	0.27	0.65	16.14	3.54	34.8
2	19.11	447	8,520	.35	.80	10.54	3.36	36.7
3	23.80	447	10,650	.43	.93	8.34	3.27	37.6
4	27.25	447	12,180	.48	1.12	7.21	3.27	37.6
5	30.50	447	13,640	.50	1.32	6.43	3.27	37.6

The same orifice and air-shutter adjustment of this burner as used in the test of city gas was also correct for coke-oven gas of this heating value. The reason for this is explained in the discussion of the Burner No. 1 when operated with coke-oven gas. Although the air shutter was completely closed, the burner received the required primary air through the openings of the loose fittings.

The analysis of the coke-oven gas used in the tests of this burner is given in Table 4.   Table 6 and Figures 16 and 17 should be self-explanatory to the reader familiar with the preceding discussion.
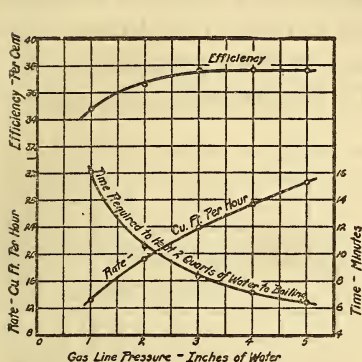

FIG. 16.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with coke-oven gas of 453 B. t. u. and burner No. 2.*

FIG. 17.—*Primary air-gas ratio obtained with coke-oven gas of 447 B. t. u. and burner No. 2 at the different conditions of operation.*
Specific gravity of gas, 0.55.

TABLE 6.—"450" B. t. u. Coke-Oven Gas, 0.54 Specific Gravity—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi-ciency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	12.18	453	5,530	0.30	0.55	15.71	3.19	38.1
2	18.44	453	8,360	.38	.77	10.55	3.23	37.5
3	22.90	453	10,380	.45	.90	8.48	3.24	37.4
4	26.62	453	12,070	.50	1.07	7.36	3.27	37.2
5	30.20	453	13,690	.53	1.23	6.80	3.42	35.5

3. TESTS OF "525" B. T. U. COAL GAS.

(*a*) BURNER NO. 1.

The coal gas used in these tests was obtained from the Philadelphia Gas Works.   The gas was received in cylinders compressed to a pressure of approximately 150 atmospheres, which probably

caused some of the illuminants to condense. It would seem that the average analysis given in Table 7 is, therefore, very similar to what should be expected if the gas were scrubbed for light oils.

To make the good adjustment of this burner it was necessary to have the air shutter about three-fourths open.

The results of the efficiency and operation tests of Burner No. 1 are given in Table 8 and Figures 18 and 19.

FIG. 18.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with coal gas of 523 B. t. u. and burner No. 1.*

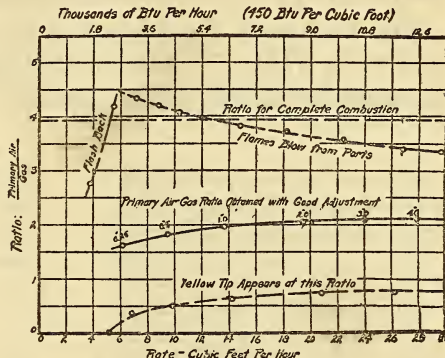FIG. 19.—*Primary air-gas ratio obtained with coal gas of 523 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.44.

TABLE 7.—Average Analysis of "525" B. t. u. Coal Gas Received from the Philadelphia Gas Works.

CO_2	per cent..	2.0
Illuminants	do....	3.3
O_2	do....	.8
CO	do....	3.2
CH_4	do....	28.9
H_2	do....	49.3
N_2	do....	7.5
Specific gravity		.444
Noncombustibles	per cent..	10.3

TABLE 8.—"525" B. t. u. Coal Gas, 0.444 Specific Gravity—Burner No. 1, 43 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	11.09	523	5,800	0.27	0.60	15.75	2.91	36.1
2	15.85	523	8,290	.34	.80	10.87	2.88	36.5
3	19.75	523	10,330	.40	1.05	8.63	2.84	37.0
4	22.78	523	11,900	.44	1.20	7.32	2.78	37.7
5	25.70	523	13,440	.48	1.30	6.74	2.89	36.4

4. TESTS OF "300" B. T. U. WATER GAS.

(a) BURNER NO. 1.

To make the good adjustment of Burner No. 1 with "300" B. t. u. water gas it was necessary to completely close the air shutter and to put a rubber sleeve over the shank of the gas cock to stop the flow of air through the hole in the air shutter. Since "300" B. t. u. water gas burns more rapidly than that of higher heating value, and since the ratio of air to gas required for complete combustion is so much less, the good adjustment occurs with a much lower ratio of primary air to gas. The ratio is about 0.6. Burner No. 1 consumed 33.5 feet[3] of gas at the good adjustment for 3 inches pressure and only required 20.1 feet[3] of primary air. If one wishes to use "300" B. t. u. water gas with this burner, it is necessary to have a tight-fitting air shutter or to reduce the gas pressure in order to reduce the injection of air into the burner.

The average analysis of the "300" B. t. u. water gas is given in Table 10.

Table 11 and Figures 22 and 23 contain the efficiency and operation data obtained with Burner No. 1.

Figure 23 is very interesting. Burner No. 1 could be made to "flash back" at all rates of consumption at which tests were made. This is the only gas that has given such results with this burner.

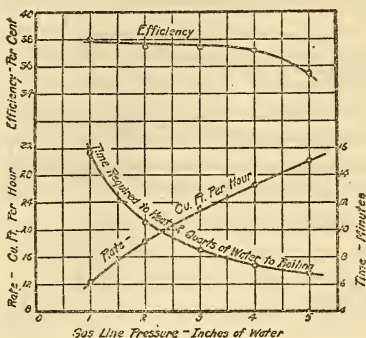FIG. 22.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 299 B. t. u. and burner No. 1.*
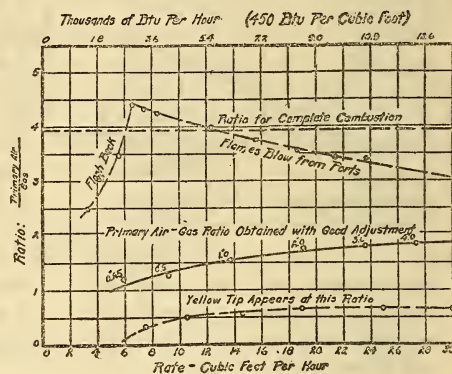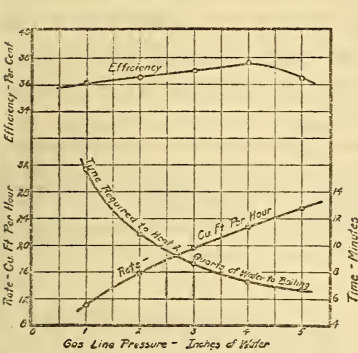

FIG. 23.—*Primary air-gas ratio obtained with water gas of 299 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.574.

TABLE 10.—Average Analysis of "300" B. t. u. Water Gas Made at Spring Gardens Plant.

CO₂	per cent..	8.2
Illuminants	do....	1.4
O₂	do....	.3
CO	do....	34.0
CH₄	do....	1.9
H₂	do....	50.4
N₂	do....	3.8
Specific gravity		.57
Noncombustibles	per cent..	12.3

TABLE 11.—"300" B. t. u. Water Gas, 0.574 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.^{3}/hr.	B.t.u./ft.^{3}	B.t.u./hr.	Inch.	Inches.	Minutes.	Feet.^{3}	Per cent.
1	19.16	299	5,730	0.20	0.50	16.29	5.20	35.4
2	26.95	299	8,060	.25	.75	11.17	5.02	36.7
3	33.46	299	10,000	.28	1.00	8.85	4.94	37.3
4	38.90	299	11,630	.32	1.10	7.48	4.85	38.0
5	42.70	299	12,780	.35	1.25	6.75	4.80	38.4

(b) BURNER NO. 2.

The good adjustment of Burner No. 2 for "300" B. t. u. water gas was made by closing the opening between the air mixer and the mixing tube with asbestos and by inserting a sheet of copper

FIG. 24.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 297 B. t. u. and burner No. 2.*
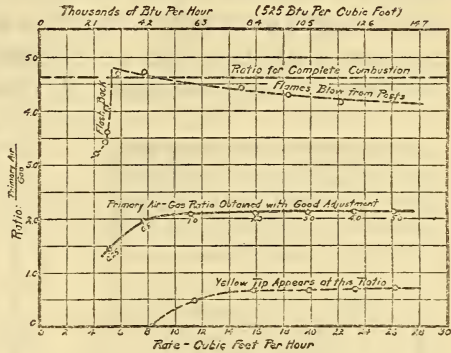

FIG. 25.—*Primary air-gas ratio obtained with water gas of 300 B. t. u. and burner No. 2 at the different conditions of operation.*
Specific gravity of gas, 0.566.

between the air-shutter cap and the air mixer. When this was done practically no air could enter the burner. All the required air for the good adjustment entered the burner through a hole about three-sixteenth inch diameter made in the sheet of copper.

The average analysis of the "300" B. t. u. water gas is given in Table 10.

Table 12 and Figures 24 and 25 give the efficiency and complete operation data of burner No. 2 with this gas.

TABLE 12.—"300" B. t. u. Water Gas, 0.566 Specific Gravity—Burner No. 2, 44
Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	18.82	297	5,590	0.20	0.55	14.65	4.59	40.3
2	26.96	297	8,000	.25	.75	10.69	4.80	38.5
3	32.89	297	9,740	.28	1.00	9.02	4.96	37.5
4	38.36	297	11,390	.32	1.25	7.91	5.04	37.0
5	43.35	297	12,880	.35	1.40	6.90	5.05	37.1

5. TESTS OF "350" B. T. U. WATER GAS.

(a) BURNER NO. 1.

With the "350" B. t. u. water gas it was necessary to have the air shutter closed. Sufficient primary air for good adjustment entered through the opening around the shank of the gas cock and a small opening that was not covered by the cap of the air shutter.

The average analysis of the "350" B. t. u. water gas is given in Table 13.

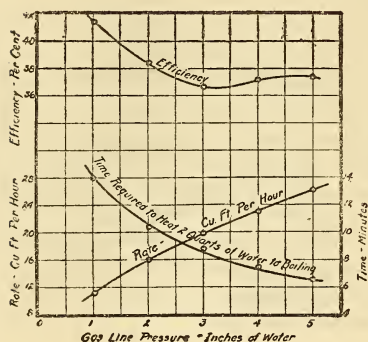The efficiency and operation data are found in Table 14 and Figures 26 and 27.

FIG. 26.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 356 B. t. u. and burner No. 1.*
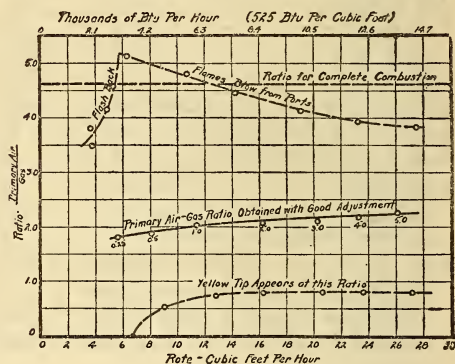

FIG. 27.—*Primary air-gas ratio obtained with water gas of 359 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.583.

TABLE 13.—Average Analysis of "350" B. t. u. Water Gas Made at Spring Gardens
Plant.

CO_2	per cent..	7.4
Illuminants	do....	3.2
O_2	do....	.7
CO	do....	34.1
CH_4	do....	3.7
H_2	do....	48.1
N_2	do....	2.8
Specific gravity		.58
Noncombustibles	per cent..	10.9

TABLE 14.—"350" B. t. u. Water Gas, 0.58 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi-ciency.
	Ft.^{3}/hr.	B.t.u./ft.^{3}	B.t.u./hr.	Inch.	Inches.	Minutes.	Feet.^{3}	Per cent.
1	14.57	356	5,190	0.22	0.55	17.47	4.25	36.4
2	21.34	356	7,600	.27	.77	11.92	4.24	36.5
3	26.00	356	9,260	.30	1.00	9.72	4.21	36.7
4	30.40	356	10,820	.35	1.20	8.18	4.15	37.3
5	34.33	356	12,230	.40	1.35	7.11	4.07	38.0

(*b*) BURNER NO. 2.

All of the primary air required for the good adjustment of Burner No. 2 with "350" B. t. u. water gas entered through the loose-fitting cap. The slot opening for the air-shutter screw was covered with a piece of sheet copper and the opening where the mixing tube enters the air mixer was closed with asbestos.

The average analysis of the "350" B. t. u. water gas is given in Table 13.

The efficiency and operation data of burner No. 2 are given in Table 15 and Figures 28 and 29.
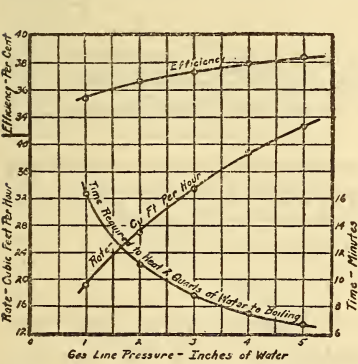

FIG. 28.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 352 B. t. u. and burner No. 2.*
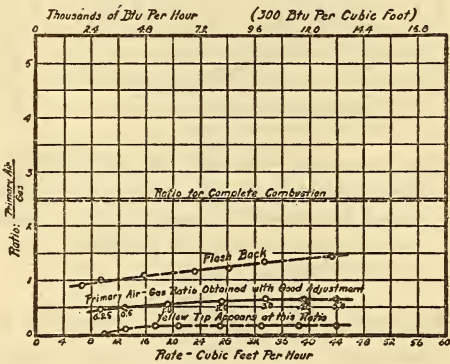

FIG. 29.—*Primary air-gas ratio obtained with water gas of 352 B. t. u. and burner No. 2 at the different conditions of operation.*

Specific gravity of gas, 0.576.

TABLE 15.—"350" B. t. u. Water Gas, 0.58 Specific Gravity—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi-ciency.
	Ft.^{3}/hr.	B.t.u./ft.^{3}	B.t.u./hr.	Inch.	Inches.	Minutes.	Feet.^{3}	Per cent.
1	13.72	352	4,830	0.25	0.60	17.29	3.95	39.6
2	21.33	352	7,510	.27	.80	11.35	4.04	38.6
3	26.04	352	9,170	.30	1.00	9.60	4.18	37.4
4	30.55	352	10,750	.33	1.15	8.29	4.22	37.2
5	34.46	352	12,130	.36	1.35	7.29	4.18	37.4

6. TESTS OF "400" B. T. U. WATER GAS.

(a) BURNER NO. 1.

To make the good adjustment with this heating value the air shutter was almost closed. The air opening was between 2 and 3 per cent of the maximum.

The average analysis of the "400" B. t. u. water gas is given in Table 16.

Table 17 and Figures 30 and 31 give the efficiency and complete operation data obtained with this burner and "400" B. t. u. water gas.
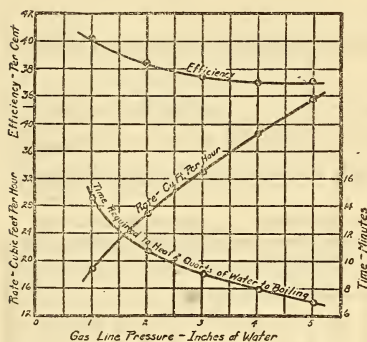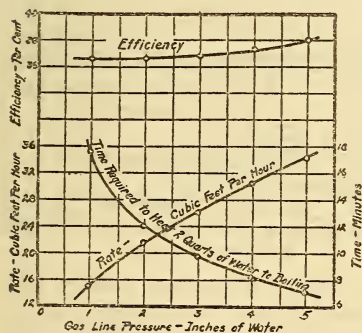

FIG. 30.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 399 B. t. u. and burner No. 1.*

FIG. 31.—*Primary air-gas ratio obtained with water gas of 406 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.585.

TABLE 16.—**Average Analysis of "400" B. t. u. Water Gas Made at Spring Gardens Plant.**

CO_2...per cent.. 6.2
Illuminants..do.... 4.5
O_2...do.... .2
CO...do...33.6
CH_4...do.... 6.4
H_2...do...43.8
N_2...do.... 5.3

Specific gravity.. .59
Noncombustibles...per cent..11.7

TABLE 17.—**"400" B. t. u. Water Gas, 0.595 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.**

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi-ciency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	13.60	399	5,420	0.25	0.54	17.01	3.86	35.6
2	19.71	399	7,870	.28	.78	11.61	3.81	36.2
2	24.42	399	9,740	.32	.95	9.19	3.74	37.0
4	28.21	399	11,260	.36	1.15	7.75	3.65	37.9
5	32.17	399	12,840	.40	1.34	6.64	3.57	38.6

(*b*) BURNER NO. 2.

This burner can not be operated with this heating value gas when adjusted at a pressure of 3 inches, even with the air shutter completely closed, unless much of the remaining primary air opening is closed. To obtain a good adjustment asbestos was used to completely close the opening where the mixing tube enters the air mixer and also to close about two-thirds of the slot opening for the air-shutter screw.

Interesting information obtained with this burner is shown by the "flash-back" curve given in Figure 33. It will be noted that the "flash-back" curve is entirely different from that obtained with Burner No. 1 (see Fig. 31) and with this same heating-value gas. It is known that the size of the ports and the com-

FIG. 32.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 401 B. t. u. and burner No. 2.*
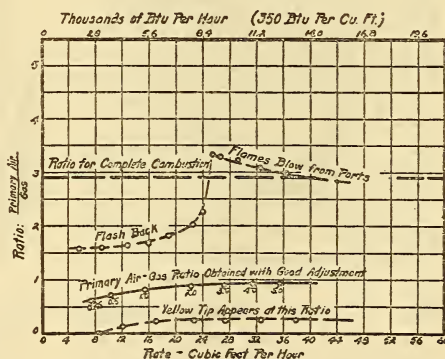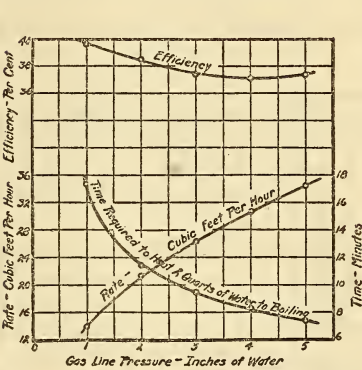

FIG. 33.—*Primary air-gas ratio obtained with water gas of 406 B. t. u. and burner No. 2 at the different conditions of operation.*
Specific gravity of gas, 0.585.

position of the gas are factors causing "flash back." Burner No. 2 has several ports larger than No. 40 drill, through which it is believed the flame flashed back under different conditions than those at which the "flash back" would have occurred if the ports were all No. 40 drill size. It would seem that gases of lower heating value tend to disclose such defects. However, these factors do not affect the operation of the burner when properly adjusted.

The average analysis of the "400" B. t. u. water gas is given in Table 16.

Table 18 and Figures 32 and 33 contain the efficiency and complete operation data obtained with this burner and "400" B. t. u. water gas.

TABLE 18.—"400" B. t. u. Water Gas, 0.595 Specific Gravity—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi-ciency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	12.85	401	5,150	0.23	0.64	16.98	3.64	37.8
2	19.18	401	7,700	.26	.88	11.32	3.62	38.0
3	23.62	401	9,470	.29	.97	9.08	3.58	38.4
4	27.54	401	11,050	.33	1.08	7.76	3.56	38.6
5	30.85	401	12,350	.36	1.25	7.10	3.65	37.7

7. TESTS OF "450" B. T. U. WATER GAS.

(a) BURNER NO. 1.

To test water gas of this heating value with Burner No. 1 the same orifice was used as in the tests of "500" B. t. u. city gas and and "450" B. t. u. coke-oven gas. At 3 inches pressure less heat units were delivered per hour than with the two above gases, but

FIG. 34.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 454 B. t. u. and burner No. 1.*
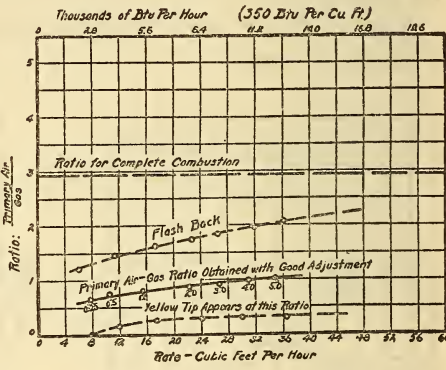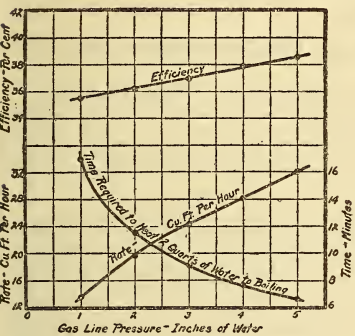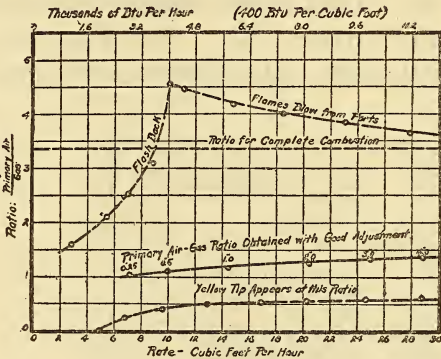

FIG. 35.—*Primary air-gas ratio obtained with water gas of 448 B. t. u. and burner No. 1 at the different conditions of operation.* Specific gravity of gas, 0.614.

it was decided that the burner still received an ample amount. In order to secure a good flame, however, the air shutter had to be closed until it was about 8 per cent open. The reason for the air-shutter readjustment will be discussed in Section VII of this report.

The average analysis of the "450" B. t. u. water gas is given in Table 19.

Table 20 and Figures 34 and 35 give the efficiency and complete operation data obtained with this burner and "450" B. t. u. water gas.

110180°—22——3

TABLE 19.—Average Analysis of "450" B. t. u. Water Gas Made at Spring Gardens Plant.

CO_2	per cent.. 5.2
Illuminants	do.... 5.6
O_2	do.... .3
CO	do....29.4
CH_4	do....10.0
H_2	do....42.2
N_2	do.... 7.3
Specific gravity	.617
Noncombustibles	per cent..12.8

TABLE 20.—"450" B. t. u. Water Gas, 0.614 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi- ciency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	11.44	454	5,200	0.25	0.55	18.04	3.44	35.3
2	16.71	454	7,590	.30	.78	11.73	3.28	37.0
3	20.75	454	9,420	.35	.90	9.37	3.24	37.4
4	24.30	454	11,040	.40	1.00	7.83	3.17	38.2
5	27.45	454	12,460	.45	1.15	6.80	3.11	39.0

(*b*) BURNER NO. 2.

The air shutter of this burner was completely closed; the same as with "450" coke-oven and "500" B. t. u. city gas, which was approximately 33 per cent coke-oven gas. The flame was harder
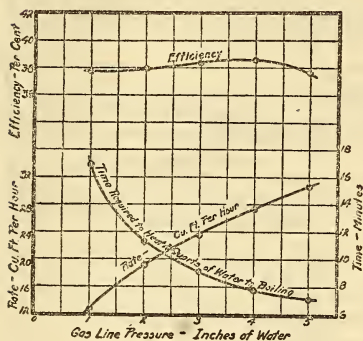

FIG. 36.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 448 B. t. u. and burner No. 2.*
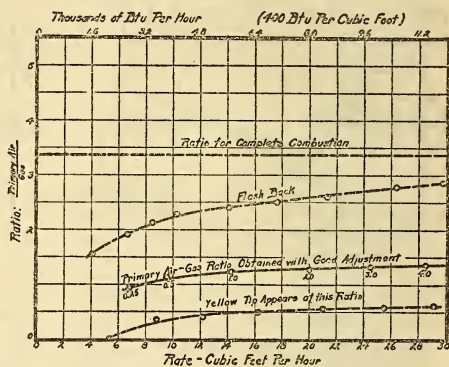

FIG. 37.—*Primary air-gas ratio obtained with water gas of 447 B. t. u. and burner No. 2 at the different conditions of operation.*

Specific gravity of gas, 0.620.

than that which we consider to be a good adjustment; but it was impossible to secure the good adjustment without stopping the flow of some of the air that entered the burner through the slot opening for the air-shutter screw or some of that which entered through the loose fitting of the air mixer. It was decided to test the burner without making any further changes, since there was no trouble from flash back when the gas was turned down.

The analysis of the "450" B. t. u. water gas is given in Table 19.

Table 21 and Figures 36 and 37 give the efficiency and complete operation data with this burner.

TABLE 21.—"450" B. t. u. Water Gas, 0.614 Specific Gravity—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	11.31	448	5,070	0.20	0.50	16.86	3.18	38.6
2	16.78	448	7,520	.25	.75	11.60	3.25	37.8
3	21.13	448	9,470	.28	.85	9.26	3.26	37.7
4	24.12	448	10,810	.30	.95	8.09	3.26	37.7
5	27.70	448	12,400	.34	1.18	7.06	3.26	37.7

8. TESTS OF "500" B. T. U. WATER GAS.

(a) BURNER NO. 1.

To make good adjustment with "500" B. t. u. water gas the air shutter was about 16 per cent open.

The average analysis of the gas is given in Table 22.

Table 23 and Figures 38 and 39 give the efficiency and complete operation data obtained with "500" B. t. u. water gas.
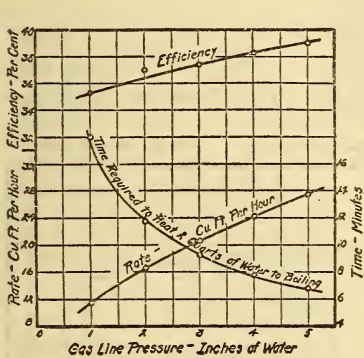

FIG. 38.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 505 B. t. u. and burner No. 1.*

FIG. 39.—*Primary air-gas ratio obtained with water gas of 501 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.633

TABLE 22.—Average Analysis of "500" B. t. u. Water Gas Made at Spring Gardens Plant.

CO_2	per cent..	5.1
Illuminants	do....	8.5
O_2	do....	.3
CO	do....	32.1
CH_4	do....	11.2
H_2	do....	38.9
N_2	do....	3.9
Specific gravity		.641
Noncombustibles	per cent..	9.3

TABLE 23.—"500" B. t. u. Water Gas, 0.634 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi- ciency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	11.11	505	5,620	0.25	0.50	16.33	3.02	36.0
2	15.82	505	8,000	.30	.75	11.15	2.94	37.1
3	19.60	505	9,900	.35	.90	8.90	2.91	37.4
4	22.86	505	11,540	.40	1.10	7.67	2.91	37.4
5	26.18	505	13,230	.45	1.30	6.67	2.91	37.5

(*b*) BURNER NO. 2.

Completely closing the air shutter allowed a little too much air to enter the burner for the good adjustment and a piece of sheet metal was inserted over the slot for the air-shutter screw which practically closed the opening.

The average analysis of the "500" B. t. u. water gas is given in Table 22.

Table 24 and Figures 40 and 41 contain the efficiency and operation data of this burner with "500" B. t. u. water gas.

FIG. 40.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 503 B. t. u. and burner No. 2.*
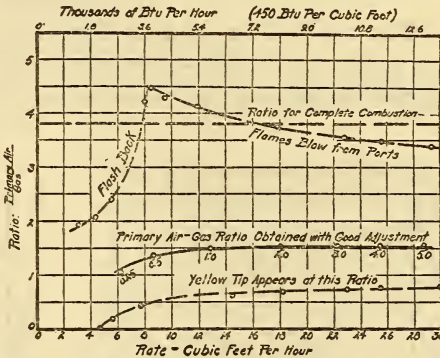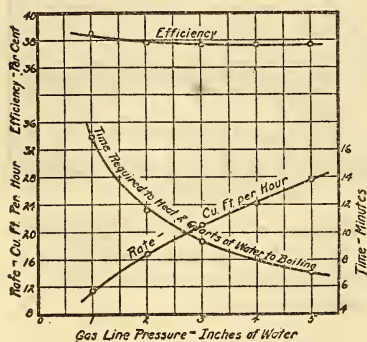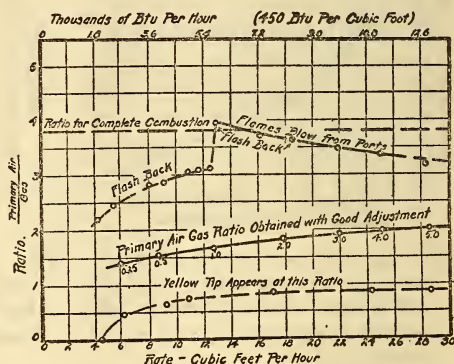

FIG. 41.—*Primary air-gas ratio obtained with water gas of 501 B. t. u. and burner No. 2 at the different conditions of operation.*
Specific gravity of gas, o.633.

TABLE 24.—"500" B. t. u. Water Gas, 0.634 Specific Gravity—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Effi- ciency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	10.91	503	5,450	0.26	0.75	16.10	2.93	37.4
2	15.24	503	7,660	.31	.85	11.60	2.95	37.1
3	18.95	503	9,540	.37	1.00	9.45	2.96	37.0
4	21.70	503	10,910	.41	1.10	8.20	2.97	36.9
5	24.98	503	12,560	.45	1.20	6.91	2.88	38.0

9. TESTS OF "550" B. T. U. WATER GAS.
(a) BURNER NO. 1.

The air shutter of Burner No. 1 was about 20 per cent open for the good adjustment with water gas of this heating value. This is the same adjustment that was made for "450" B. t. u. coke-oven and "500" B. t. u. city gas, but the "450" B. t. u. coke-oven gas had a specific gravity of 0.55, the "500" B. t. u. city gas a specific gravity of 0.62, and the "550" water gas a specific gravity of 0.66.

The average analysis of "440" B. t. u. water gas is given in Table 25.

Table 26 and Figures 42 and 43 give the efficiency and complete operation data of Burner No. 1 with "550" B. t. u. water gas.
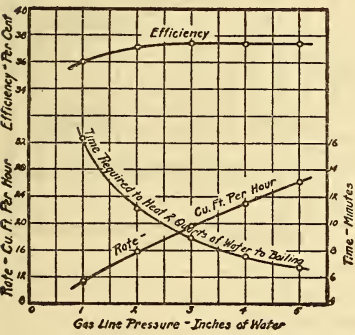

FIG. 42.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 557 B. t. u. and burner No. 1.*
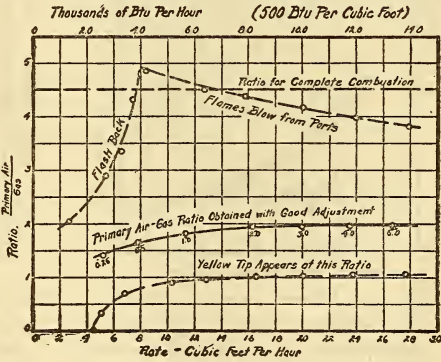
FIG. 43.—*Primary air-gas ratio obtained with water gas of 558 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.662.

TABLE 25.—Average Analysis of "550" B. t. u. Water Gas Made at Spring Gardens Plant.

CO_2	per cent..	4. 2
Illuminants	do....	10. 7
O_2	do....	. 2
CO	do....	32. 0
CH_4	do....	12. 7
H_2	do....	35. 5
N_2	do....	4. 7
Specific gravity		. 66
Noncombustibles	per cent..	9. 1

TABLE 26.—"550" B. t. u. Water Gas, 0.657 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	9. 69	549	5,300	0.25	0.50	17. 79	2. 87	35. 0
2	13. 95	549	7,660	. 30	. 70	12. 00	2. 78	36. 1
3	16. 68	557	9,290	. 35	. 90	9. 51	2. 64	37. 3
4	19. 33	557	10,930	. 40	1. 10	8. 05	2. 59	38. 1
5	22. 22	557	12,390	. 45	1. 30	6. 86	2. 54	38. 9

(b) BURNER No. 2.

Completely closing the air shutter still allowed a little too much air to enter the burner. The flame was a little too hard, so a piece of thin sheet metal was inserted between the air-shutter cap and air mixer, and over the slot for the air-shutter screw. This was not the equivalent of closing the slot because the piece of inserted sheet metal did not permit as close a fit between the air-shutter cap and air-shutter mixer as there was before the insertion.

The analysis of the "550" B. t. u. water gas is given in Table 25.

Table 27 and Figures 44 and 45 give the efficiency and operation data obtained with Burner No. 2 and "550" B. t. u. water gas.
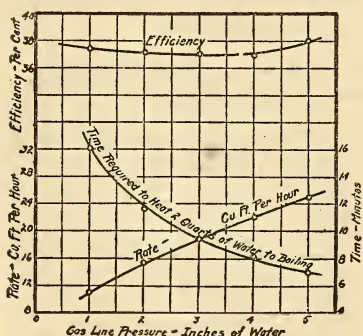

FIG. 44.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 549 B. t. u. and burner No. 2.*
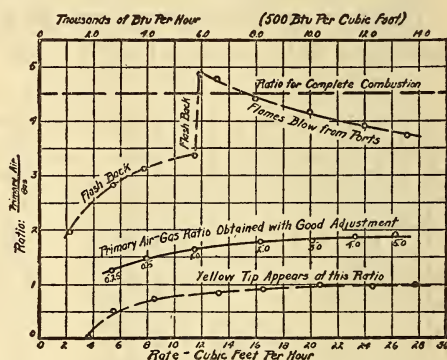
FIG. 45.—*Primary air-gas ratio obtained with water gas of 552 B. t. u. and burner No. 2 at the different conditions of operation.*
Specific gravity of gas, 0.662.

TABLE 27.—"550" B. t. u. Water Gas, 0.657 Specific Gravity—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	9.31	549	5,110	0.25	0.50	17.45	2.71	37.0
2	13.54	549	7,440	.30	.70	11.70	2.64	38.0
3	16.68	549	9,160	.35	.90	9.57	2.66	37.7
4	19.45	549	10,690	.40	1.10	8.30	2.70	37.0
5	22.61	549	12,420	.43	1.28	7.40	2.78	36.0

10. TESTS OF "600" B. T. U. WATER GAS.

(a) BURNER No. 1.

The air-shutter setting for the good adjustment of Burner No. 1 was about 50 per cent open. After the tests were in progress it was observed that if one opening of the air shutter was closed by

holding a finger over it the flame was slightly harder than that of the good adjustment.   This is contrary to what should be expected when half of the primary air opening is closed after a good adjustment is made.   The cause of the irregularity was not thoroughly investigated, but is believed that it was caused by a slight disalignment of the gas stream with the injecting tube of the burner. This matter does not affect our results, but shows the importance of having the gas stream in correct alignment with the injecting tube of the burner where burners are operated with a very low pressure and gas of a high heating value, otherwise sufficient air may not be injected into the burner to secure a good flame.

The average analysis of "600" B. t. u. water gas is given in Table 28.

Table 29 and Figures 46 and 47 give the efficiency and complete operation data of Burner No. 1 with "600" B. t. u. water gas.
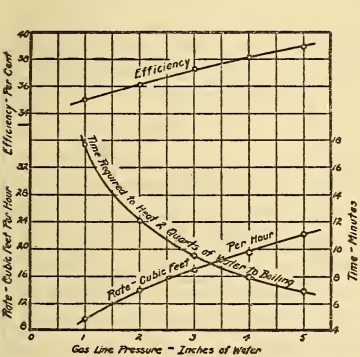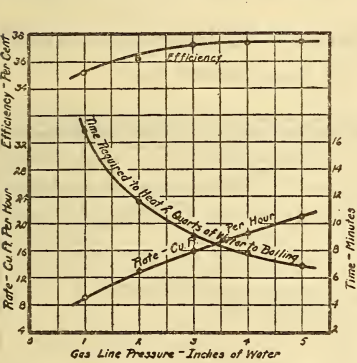

FIG. 46.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 608 B. t. u. and burner No. 1.*
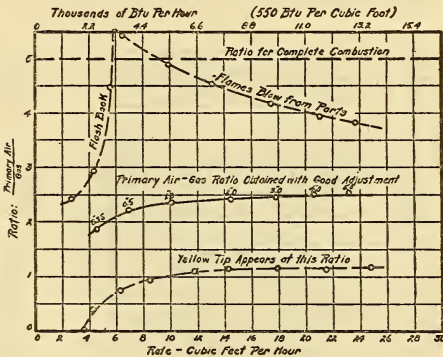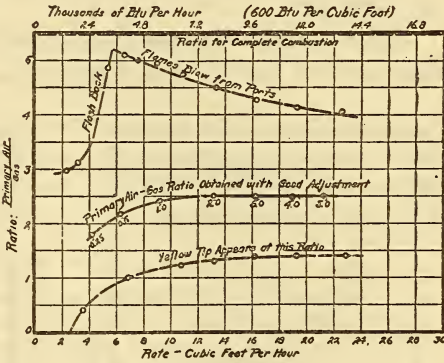
FIG. 47.—*Primary air-gas ratio obtained with water gas of 608 B. t. u. and burner No. 1 at the different conditions of operation.*

Specific gravity of gas, 0.682.

TABLE 23.—**Average Analysis of "600" B. t. u. Water Gas Made at Spring Gardens Plant.**

CO_2	Per cent..	4. 8
Illuminants	do....	12. 8
O_2	do....	. 3
CO	do....	29. 2
CH_4	do....	14. 2
H_2	do....	35. 0
N_2	do....	3. 7
Specific gravity		. 676
Noncombustibles	Per cent..	8. 8

TABLE 29.—"600" B. t. u. Water Gas, 0.682 Specific Gravity—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	9.17	608	5,500	0.25	0.50	16.85	2.57	35.2
2	12.91	608	7,860	.33	.75	11.77	2.50	36.2
3	15.92	608	9,680	.40	.95	9.14	2.43	37.3
4	18.50	608	11,250	.45	1.15	7.85	2.42	37.4
5	21.03	608	12,800	.50	1.35	6.90	2.42	37.5

(b) BURNER No. 2.

The air shutter was completely closed for the good adjustment of Burner No. 2 because enough primary air entered the burner through the slot for the air-shutter screw, the loose-fitting shutter, and the opening where the mixing tube enters the air mixer.

The average analysis of the "600" B. t. u. water gas is given in Table 28.

Table 30 and Figures 48 and 49 contain the efficiency and operation data of Burner No. 2 with "600" B. t. u. water gas.
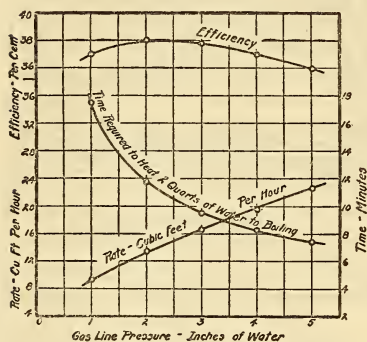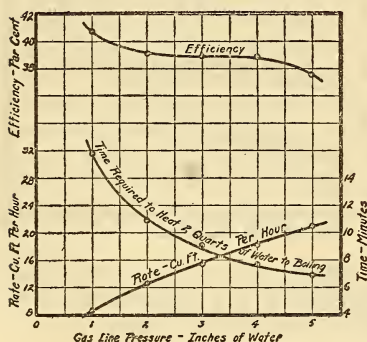

FIG. 48.—*Curves showing efficiency, time required, and cubic feet of gas used to heat 2 quarts of water to boiling with water gas of 608 B. t. u. and burner No. 2.*
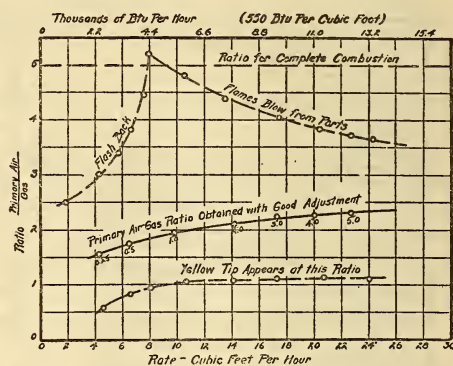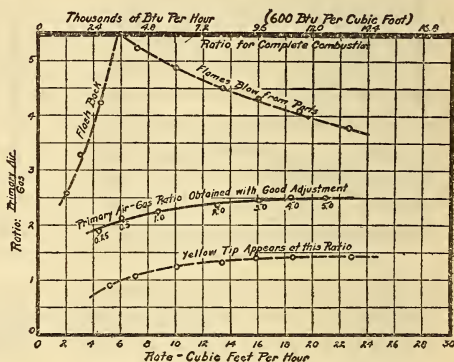
FIG. 49.—*Primary air-gas ratio obtained with water gas of 608 B. t. u. and burner No. 2 at the different conditions of operation.*

Specific gravity of gas, 0.680.

TABLE 30.—"600" B. t. u. Water Gas, 0.680 Specific Gravity—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

Pressure in inches of water.	Gas rate.	Heating value.	Quantity of heat supplied.	Cone height.	Flame height.	Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
	Ft.³/hr.	B. t. u./ft.³	B. t. u./hr.	Inch.	Inches.	Minutes.	Feet.³	Per cent.
1	8.68	608	5,280	0.30	0.60	15.35	2.22	40.7
2	12.80	608	7,780	.35	.80	10.86	2.32	39.0
3	15.40	608	9,360	.40	.95	9.10	2.33	38.9
4	18.18	608	11,050	.45	1.15	7.89	2.33	38.9
5	20.89	608	12,700	.50	1.35	6.91	2.40	37.6

11. TESTS FOR CARBON MONOXIDE IN THE PRODUCTS OF COMBUSTION.

The products of combustion from the preceding tests were analyzed in order to determine whether any carbon monoxide was produced. The analyses show that with the "regular" burners used on gas ranges, when properly adjusted, practically no carbon monoxide was produced with any of the gases tested unless gas was burned at a rate greater than about 12,000 B. t. u./hr. Since gas is seldom burned above this rate with burners of "regular" size the danger from carbon-monoxide poisoning is very remote if the burners are properly adjusted. When gas was burned above this rate, the amount of carbon monoxide produced was such as would cause headaches in a poorly ventilated room.

For the larger top burners, which are commonly designated as "giant" burners, the limitation of 12,000 B. t. u./hr. does not apply, although no tests have been made to determine the maximum safe consumption for these burners.

The heating value of the gas or the kind of gas did not seem to be factors affecting the production of carbon monoxide.

12. SUMMARY OF GAS ANALYSES.

The average analyses of the different gases tested are given in Table 31. To make the theoretical calculations shown at the bottom of the table, it was assumed that the constituents of the illuminants of water gas averaged $C_{2.6} H_{6.6}$, and that the illuminants of coke-oven and coal gas averaged $C_2 H_5$.

TABLE 31.—Average Analyses of Gases Tested at Spring Gardens.

Kind of gas	City gas.[1]	Coke-oven gas.	Coal gas.	Water gas.						
Nominal heating value (B. t. u. per cubic foot)	500	450	525	300	350	400	450	500	550	600
Constituents:										
CO₂......per cent..	4.1	3.2	2.0	8.2	7.4	6.2	5.2	5.1	4.2	4.8
Ill......do....	6.5	3.0	3.3	1.4	3.2	4.5	5.6	8.5	10.7	12.8
O₂......do....	.8	1.0	.8	.3	.7	.2	.3	.3	.2	.3
CO......do....	21.5	9.6	8.2	34.0	34.1	33.6	29.4	32.1	32.0	29.2
CH₄......do....	16.2	22.8	28.9	1.9	3.7	6.4	10.0	11.2	12.7	14.2
H₂......do....	36.6	41.5	49.3	50.4	48.1	43.8	42.2	38.9	35.5	35.0
N₂......do....	14.3	18.9	7.5	3.8	2.8	5.3	7.3	3.9	4.7	3.7
Heating value (B. t. u. per cubic foot, calorimeter)	496	450	524	298	354	400	451	501	556	603
Specific gravity (air=1.0)	0.619	0.542	0.444	0.570	0.580	0.590	0.617	0.641	0.660	0.676
Noncombustibles......per cent..	10.2	23.1	10.3	12.3	10.90	11.7	12.8	9.3	9.1	8.8
Required for complete combustion of 1 ft.³ of gas... O₂ cubic feet..	.883	.799	.965	.516	.613	.704	.793	.940	1.094	1.148
air cubic feet..	4.22	3.82	4.61	2.46	2.93	3.36	3.79	4.49	4.99	5.47
Cubic feet CO₂ produced by combustion... per cubic foot of gas........	.587	.416	.457	.477	.535	.579	.591	.705	.767	.815
per 1,000 B.t.u.	1.48	.925	.872	1.60	1.51	1.45	1.31	1.41	1.38	1.35
Cubic feet water vapor produced by combustion... per cubic foot of gas........	.905	.946	1.15	.588	.661	.715	.807	.894	.962	1.06
per 1,000 B.t.u.	1.83	2.10	2.20	1.97	1.87	1.79	1.79	1.79	1.73	1.76

[1] City gas contained approximately one-third coke-oven gas and two-thirds water gas.

13. COMPARISON OF RESULTS WITH GASES OF DIFFERENT HEATING VALUES.

1. Within the range of gas consumption normally used in top-burner cooking there will be some variations in the efficiency with the rate of heating. Since this is the case, it appears logical that for an exact comparison of the efficiencies of gases of different heating values the burners must be supplied with the same total quantity of heat units per hour.

2. From observations made by the bureau during service investigations in a large number of cities and from laboratory tests made at the bureau it has been observed that a good average adjustment on a regular burner will represent a consumption of about 9,000 B. t. u./hr. An adjustment for this rate will allow a variation in gas pressure which will be within the usual legal requirements without causing poor service or loss in efficiency. For an example, a burner adjusted to 9,000 B. t. u. at 3 inches pressure will consume 7,000 B. t. u. at 1.8 inches and will not exceed 11,000 B. t. u. at 4.4 inches pressure.

TABLE 32.—Summary of Tests for Rate of Consumption of 7,000 B. t. u. per Hour—Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

CITY GAS (ONE-THIRD COKE-OVEN GAS, TWO-THIRDS WATER GAS).

| Heating value. | | Specific gravity (air=1). | Gas rate (actual). | Good adjustment of burner. | | Time. required to heat 2 quarts of water from 80 to 212° F. | Gas used. | Efficiency. |
Nominal.	Actual.			Primary air-gas ratio.	B. t. u. per cubic foot of mixture.			
B. t. u./ft.³ 500	B. t. u./ft.³ 492	0.618	Ft.³/hr. 14.23	2.15	156	Minutes. 13.2	Foot.³ 3.12	Per cent. 35.8

COKE-OVEN GAS.

450	447	0.55	15.66	2.0	149	13.3	3.46	35.6

COAL GAS.

525	523	0.444	13.38	2.10	169	13.0	2.90	36.3

WATER GAS.

300	299	0.574	23.40	0.58	189	13.1	5.10	36.1
350	356	.583	19.65	.88	189	13.0	4.25	36.4
400	399	.595	17.54	1.26	177	13.1	3.83	36.0
450	454	.614	15.42	1.52	180	13.0	3.33	36.4
500	505	.634	13.86	1.90	179	12.9	2.97	36.6
550	557	.657	12.57	2.40	164	13.2	2.77	35.7
600	608	.682	11.51	2.47	175	13.2	2.53	35.8

TABLE 33.—Summary of Tests for Rate of Consumption of 9,000 B. t. u. per Hour—
Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

CITY GAS (ONE-THIRD COKE-OVEN GAS, TWO-THIRDS WATER GAS).

Heating value.		Specific gravity (air=1).	Gas rate (actual).	Good adjustment of burner.		Time. required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
Nominal.	Actual.			Primary air-gas ratio.	B. t. u. per cubic foot of mixture.			
B. t. u./ft.³ 500	B.t.u./ft.³ 492	0.618	Ft.³/hr. 18.30	2.23	153	Minutes. 10.0	Foot.³ 3.05	Per cent. 36.6

COKE-OVEN GAS.

| 450 | 447 | 0.55 | 20.12 | 2.06 | 146 | 9.9 | 3.33 | 36.9 |

COAL GAS.

| 525 | 523 | 0.444 | 17.20 | 2.10 | 169 | 10.0 | 2.86 | 36.7 |

WATER GAS.

300	299	0.574	30.10	0.61	186	9.9	4.97	37.0
350	356	.583	25.28	.92	185	10.0	4.21	36.7
400	399	.595	22.55	1.32	172	10.0	3.75	36.7
450	454	.614	19.81	1.53	180	9.9	3.26	37.2
500	505	.634	17.83	1.95	171	9.8	2.85	37.3
550	557	.657	16.16	2.45	161	9.9	2.66	37.1
600	608	.682	14.80	2.48	175	10.0	2.46	36.8

TABLE 34.—Summary of Tests for Rate of Consumption of 11,000 B. t. u. per Hour—
Burner No. 1, 48 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

CITY GAS (ONE-THIRD COKE-OVEN GAS, TWO-THIRDS WATER GAS).

Heating value.		Specific gravity (air=1).	Gas rate (actual).	Good adjustment of burner.		Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
Nominal.	Actual.			Primary air-gas ratio.	B. t. u. per cubic foot of mixture.			
B. t. u./ft.³ 500	B.t.u./ft.³ 492	0.618	Ft.³/hr. 22.35	2.28	150	Minutes. 7.9	Feet.³ 2.94	Per cent. 38.0

COKE-OVEN GAS.

| 450 | 447 | 0.55 | 24.60 | 2.10 | 144 | 8.0 | 3.27 | 37.6 |

COAL GAS.

| 525 | 523 | 0.444 | 21.03 | 2.12 | 168 | 8.0 | 2.82 | 37.3 |

WATER GAS.

300	299	0.574	36.80	0.63	184	8.0	4.88	37.7
350	356	.583	30.90	.95	183	8.0	4.13	37.4
400	399	.595	27.57	1.36	169	8.0	3.67	37.6
450	454	.614	24.22	1.54	179	7.9	3.17	38.2
500	505	.634	21.78	1.96	171	8.0	2.91	37.4
550	557	.657	19.75	2.48	160	7.9	2.58	38.2
600	608	.682	18.09	2.48	177	8.0	2.42	37.4

The results of tests of the gases of various heating values with Burner No. 1 for rates of consumption of 7,000, 9,000, and 11,000 B. t. u./hr. are shown in Tables 32, 33, and 34, respectively.

Values of efficiency obtained with the various heating values, the corresponding rates of consumption in cubic feet per hour, and the time required to heat 2 quarts of water to boiling from 80° F., as given in Table 33 (9,000 B. t. u./hr.), have been plotted in Figure 50. The tests proved conclusively that when the regular burner No. 1, which is placed 1⅜ inches from the utensil, consumed gas
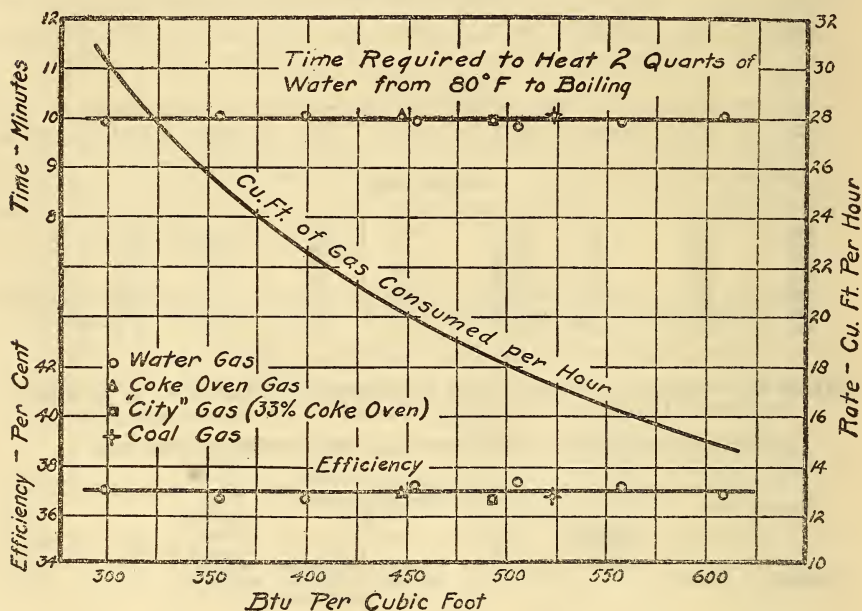
FIG. 50.—*Curves showing efficiency, rate of consumption, and time required to heat 2 quarts of water from 80° F. to boiling when burner No. 1 is operated at 9,000 B. t. u. per hour with gases of various heating values.*

at the rate of 9,000 B. t. u./hr., all the different gases, irrespective of the kind of gas or B. t. u. content per cubic foot, gave a constant efficiency of about 37 per cent, at least within the range of heating values used in these tests (300 to 600 B. t. u.). The time required to heat 2 quarts of water to boiling from 80° F. with 9,000 B. t. u./hr. was about 10 minutes.

At a rate of 7,000 B. t. u./hr. an average efficiency of about 36 per cent was obtained (see Table 32), and about 13 minutes were required to heat 2 quarts of water to boiling from 80° F. For a rate of 11,000 B. t. u./hr. the average efficiency was about 37.7 per cent (see Table 34), and the time required to heat 2 quarts of

water to boiling from 80° F. was about 8 minutes. These results show that the efficiency of heat absorption varies only slightly with a change in the rate of heat supply. It follows, therefore, that the rate of heating varies almost directly with the rate of supply of heat.

<center>(b) RESULTS WITH BURNER NO. 2.</center>

The efficiencies obtained with the gases of different heating value when Burner No. 2 was used are very similar to those obtained with Burner No. 1. Both burners were 1⅜ inches from top of
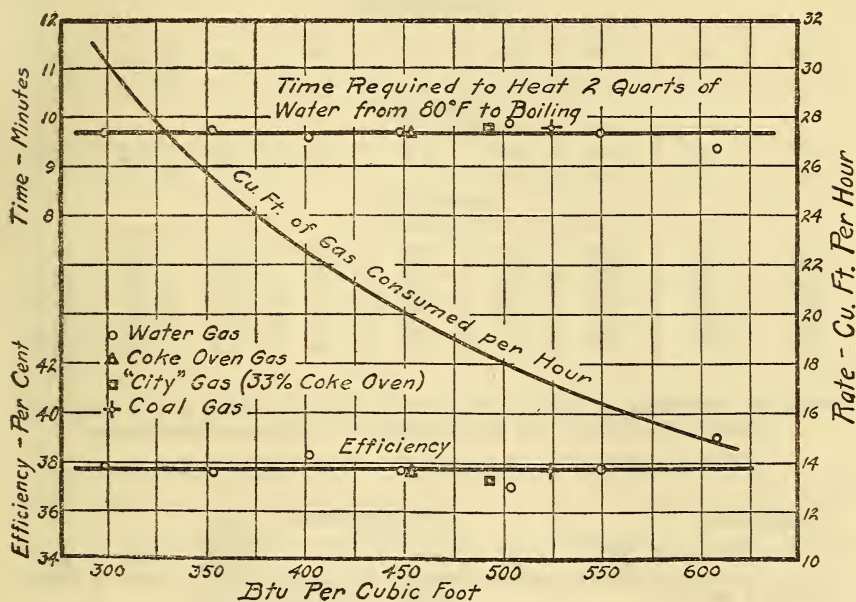
FIG. 51.—*Curves showing efficiency, rate of consumption, and time required to heat 2 quarts of water from 80° F. to boiling when burner No. 2 is operated at 9,000 B. t. u. per hour with gases of various heating values.*

grid (bottom of utensil), but Burner No. 2 has four ports less than No. 1 and is 3⅝ inches in diameter, while No. 1 is 4¼ inches in diameter.

Tables 35, 36, and 37, for rates of consumption of 7,000, 9,000, and 11,000 B. t. u./hr., respectively, show the efficiencies and operation data obtained with the gases of different heating values with this burner. Values from Table 36 (9,000 B. t. u./hr.) have been plotted in Figure 51. The results show that with gases of different heating value and a consumption of 9,000 B. t. u./hr. an average efficiency of about 37.8 per cent was obtained and the time required to heat 2 quarts of water to boiling from 80° F. was about 9.7 minutes.

TABLE 35.—Summary of Tests for Rate of Consumption of 7,000 B. t. u. per Hour—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

CITY GAS (ONE-THIRD COKE-OVEN GAS, TWO-THIRDS WATER GAS).

Heating value.		Specific gravity (air=1).	Gas rate (actual).	Good adjustment of burner.		Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
Nominal.	Actual.			Primary air-gas ratio.	B.t.u. per cubic foot of mixture.			
B.t.u./ft.³	B.t.u./ft.³		Ft.³/hr.			Minutes.	Feet.³	Per cent.
500	492	0.624	14.22	1.81	175	12.8	3.02	37.0

COKE-OVEN GAS.

450	453	0.54	15.45	1.61	173	12.5	3.22	37.7

COAL GAS.

525	524	0.444	13.25	2.05	172	11.8	2.63	39.9

WATER GAS.

300	297	0.566	23.57	0.51	197	12.1	4.74	39.1
350	352	.576	19.88	.84	191	12.2	4.05	38.6
400	401	.595	17.45	1.27	177	12.5	3.62	37.9
450	448	.614	15.63	1.77	162	12.4	3.23	38.0
500	503	.634	13.91	1.73	184	12.7	2.94	37.2
550	549	.657	12.75	2.08	178	12.5	2.64	37.9
600	608	.680	11.51	2.37	181	12.0	2.30	39.4

TABLE 36.—Summary of Tests for Rate of Consumption of 9,000 B. t. u. per Hour—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

CITY GAS (ONE-THIRD COKE-OVEN GAS, TWO-THIRDS WATER GAS).

Heating value.		Specific gravity (air=1).	Gas rate (actual).	Good adjustment of burner.		Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
Nominal.	Actual.			Primary air-gas ratio.	B.t.u. per cubic foot of mixture.			
B.t.u./ft.³	B.t.u./ft.³		Ft.³/hr.			Minutes.	Feet.³	Per cent.
500	492	0.624	18.30	1.87	171	9.8	3.00	37.3

COKE-OVEN GAS.

450	453	0.54	19.86	1.73	166	9.7	3.22	37.7

COAL GAS.

525	524	0.444	17.16	2.12	168	9.7	2.78	37.8

WATER GAS.

300	297	0.566	30.30	0.52	195	9.7	4.89	37.9
350	352	.576	25.58	.90	185	9.8	4.15	37.6
400	401	.595	22.44	1.30	174	9.6	3.58	38.3
450	448	.614	20.10	1.87	156	9.7	3.26	37.7
500	503	.634	17.89	1.81	179	9.9	2.95	37.0
550	549	.657	16.40	2.18	173	9.7	2.65	37.8
600	608	.680	14.80	2.45	176	9.4	2.33	38.9

TABLE 37.—Summary of Tests for Rate of Consumption of 11,000 B. t. u. per Hour—Burner No. 2, 44 Ports, No. 40 Drill—Utensil 1 3/8 Inches from Burner.

CITY GAS (ONE-THIRD COKE-OVEN GAS, TWO-THIRDS WATER GAS).

Heating value.		Specific gravity (air=1).	Gas rate (actual).	Good adjustment of burner.		Time required to heat 2 quarts of water from 80 to 212° F.	Gas used.	Efficiency.
Nominal.	Actual.			Primary air-gas ratio.	B. t. u. per cubic foot of mixture.			
B. t. u./ft.³ 500	B. t. u./ft.³ 492	0.624	Ft.³/hr. 22.35	1.90	170	Minutes. 8.0	Feet.³ 2.98	Per cent. 37.5

COKE-OVEN GAS.

450	453	0.540	24.28	1.81	161	8.0	3.24	37.5

COAL GAS.

525	524	0.444	21.0	2.18	165	8.2	2.86	36.7

WATER GAS.

300	297	0.566	37.03	0.53	194	8.1	4.99	37.1
350	352	.576	31.25	.99	177	8.1	4.21	37.1
400	401	.595	27.42	1.35	171	7.8	3.55	38.6
450	448	.614	24.54	1.94	153	8.0	3.26	37.6
500	503	.634	21.86	1.85	176	8.1	2.96	36.9
550	549	.657	20.03	2.27	168	8.1	2.72	36.9
600	608	.680	18.08	2.48	175	7.7	2.32	38.9

(c) EFFECT OF ROOM TEMPERATURE ON EFFICIENCY TESTS.

Some investigators claim that in order to get consistent and reproducible results in the efficiency values it is necessary to have a very constant room temperature. In these tests it was impossible to control the room temperature, but in making a study of the efficiency results and the room temperature at the time of the tests, it is impossible to find any indication that the variation in temperature affected the results.

Table 38 shows average room temperatures during the time that each series of efficiency tests were made.

TABLE 38.—Average Room Temperatures During Efficiency Tests.

Kind of gas.............	Water gas.							City gas.	Coke-oven gas.	Coal gas.
Nominal heating value (B. t. u. per cubic foot).	300	350	400	450	500	550	600	500	450	525
Room temperature: Burner No. 1...............	82	86	94	98	83	87	82	80	84	75
Burner No. 2...............	79	86	99	92	79	88	83	89	85	77

14. ADJUSTMENT OF BURNERS FOR GASES OF DIFFERENT HEATING VALUE AND SPECIFIC GRAVITY.

The different factors that enter into the proper adjustment of a burner are (1) heating value of the gas; (2) quantity of heat required; (3) kind of gas; (4) gas pressure; (5) specific gravity; and (6) type of air mixer, air shutter, injecting tube, and size of orifice.

The heating value determines the volume of gas that must be supplied the burner. A change of heating value changes the ratio of primary air to gas required for a good flame, and generally necessitates a change of size of orifice and the position of the air shutter.

The kind of gas affects the ease of operation of a burner. Coal and coke oven gas are less susceptible to flash back than water gas, which means that the range of adjustment for good operation is greater than with water gas.

The volume of air injected into a burner is dependent upon the energy of the gas stream, which varies with the volume consumed, the pressure, and the specific gravity of the gas. A change of any one of these factors may necessitate a change of the orifice and the air-shutter position.

The range of heating value to which the burners can be adjusted will depend upon the pressure of the gas, the design of air mixer, air shutter, and injecting tube. There are a few burners of obsolete design in service which do not have an adjustable air shutter and it is more difficult to make adjustments for low heating value gases with such burners.

(a) ADJUSTMENT OF BURNER NO. 1.

The adjustment of Burner No. 1 to consume gases of different heating values warrants the conclusion that the burner can be used without alteration to give good service with water gas of a heating value as low as 350 B. t. u./ft.³ The adjustment for each of the different heating values was made when the pressure was 3 inches. This burner is representative of the "star" type. Star burners are most widely used.

(b) ADJUSTMENT OF BURNER NO. 2.

Burner No. 2, which was tested, and which is shown in Figure 2, is one of the older designs and is of the "disk" type. On account of its loose fitting air mixer and air shutter it could not be used with water gas of a heating value lower than about 450 B. t. u. and a pressure of 3 inches without devising some means to obstruct the flow of primary air into the burner.

V. GAS PRESSURE NECESSARY FOR GOOD ADJUSTMENT OF BURNER NO. 1 WITH "500" AND "600" B. T. U. WATER GAS.

When the air shutter of a burner must be partly or almost completely closed to obtain a "good adjustment" it indicates that the burner could be operated equally as well at a lower pressure by using a larger orifice and a larger opening of the air shutter. It is interesting to know what is the minimum pressure required to produce a good flame when the air shutter is in the wide-open position.

FIG. 52.—*Air-gas ratios obtained at different pressures and gas rates with burner No. 1 when operated with water gas of 501 B. t. u.*

Specific gravity of gas, 0.633. Air shutter wide open.

The required pressure will vary with (1) the design of injecting tube of burner, (2) the type of orifice (fixed orifices require less pressure than adjustable orifices), (3) the specific gravity of the gas, and (4) the heating value of the gas.

TEST NO. 1.—Conditions of test: (1) Air shutter wide open, (2) specific gravity of gas 0.633, (3) water gas, 501 B. t. u./ft.^{3}, and (4) fixed orifices (sharp-edge type).

Figure 52 shows the ratios of air to gas that were obtained with different rates of consumption and pressures of 0.5, 1, 2, 3, 4, and

5 inches when the air shutter was wide open. Orifices of different sizes were used in order to determine these curves. This figure shows that when the gas pressure is constant and the gas rate is changed by changing the size of the orifice, the air-gas ratio decreases as the gas rate increases. Thus the minimum pressure required to produce the proper air-gas ratio is the pressure that will give a good adjustment at the maximum rate at which the burner is to be operated. If 10,000 heat units per hour are taken as the correct consumption for a regular burner, the gas rate
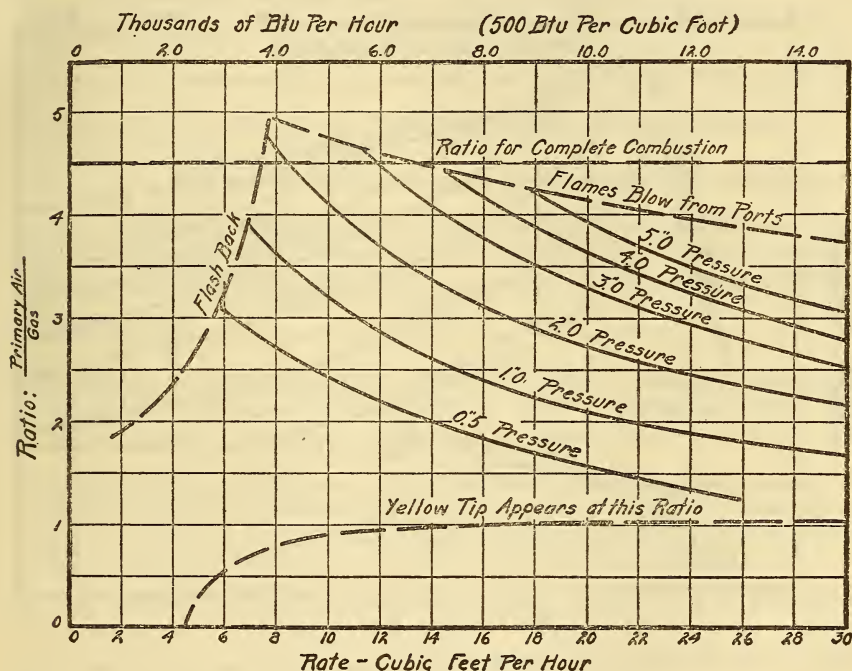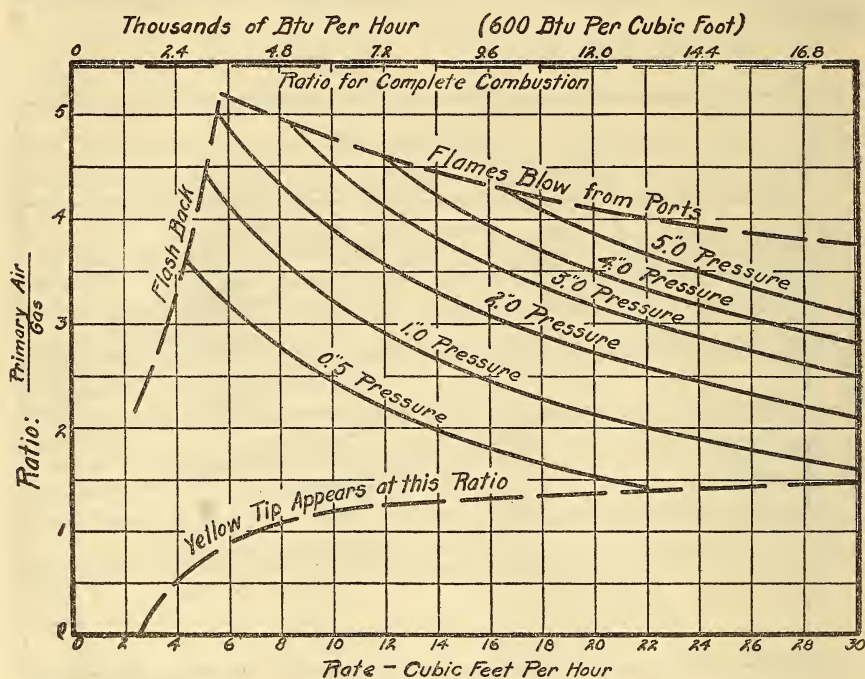

Fig. 53.—*Air-gas ratios obtained at different pressures and gas rates with burner No. 1 when operated with water gas of 608 B. t. u.*

Specific gravity of gas, 0.682. Air shutter wide open.

with 500 B. t. u. gas will be 20 ft.³/hr. From Figure 39, the tests of which were made with 500 B. t. u. water gas, it will be noted that the "good adjustment" at this rate is secured with an air-gas ratio of 1.95. Figure 52 shows that when the air shutter is wide open a pressure of about seventh-eighth inch will produce this air-gas ratio at a gas rate of 20 ft.³/hr. A pressure of 1 inch, therefore, is sufficient to inject the proper amount of air when the burner is supplied with not more than 10,000 B. t. u./hr.

It follows that Burner No. 1, if operated with water gas of 0.63 specific gravity and "500" B. t. u./ft.³, would not need an ad-

justment of the air shutter if the pressure at the orifice were 1 inch. If one wishes to operate the burners now in use with a pressure of 1 inch, it would be necessary to increase the size of orifice and open the air shutter to obtain a good flame.

TEST No. 2.—Conditions of test: (1) Air shutter wide open, (2) specific gravity of gas 0.682, (3) water gas—608 B. t. u./ft.³, and (4) fixed orifices (sharp-edged type).

The results of this test are shown by Figure 53. The curves of this figure must be compared with the "good adjustment" curve of Figure 47 which was made with the same gas. Figure 47 shows that an air-gas ratio of 2.5 corresponds to a "good adjustment" with "600" B. t. u. water gas. Figure 53 shows that if the air shutter had been wide open, a pressure of about 1¼ inches would have produced the same good adjustment for a consumption of 10,000 B. t. u./hr. (16.7 ft.³).

No tests of this kind were made with Burner No. 2 because it could not be conveniently tested with our equipment. It is believed that an allowance of about one-fourth inch more pressure should be made for Burner No. 2 on account of the design of the injecting tube.

VI. EFFECT OF CHANGE IN HEATING VALUE ON THE FLAME CHARACTERISTICS AND OPERATION OF BURNERS.

1. COMPARISON OF AIR-GAS RATIO AND B. T. U. PER CUBIC FOOT OF MIXTURE WITH WATER GAS OF 400, 500, AND 600 B. T. U. AND COAL GAS OF 525 B. T. U. AT THE UPPER WORKABLE LIMIT, GOOD ADJUSTMENT, AND CONDITIONS AT WHICH YELLOW TIP APPEARS.

The effect of gases of different heating values on the operation of a burner is best shown by curves. Figures 54, 55, 56, and 57 show the data obtained with water gas of 400, 500, and 600 B. t. u. and coal gas of 525 B. t. u. The curves labeled "Flash back," "Flames blow from ports," "Primary air-gas ratio obtained with good adjustment," and "Yellow tip appears at this ratio" have been discussed in a previous section of this report. However, it is well to mention here that the air-gas ratio varies for each particular curve, depending on the heating value of gas used and that there is a slight increase in the range of adjustment (from "yellow tip" to "upper limit of workable adjustment") as the heating value of water gas increases. The curves marked "Upper limit of workable adjustment," were obtained when the air shutter was so adjusted that an explosion did not occur when the gas was turned off from the "on full" position of the gas cock, except when

the gas cock was turned off very suddenly. A burner that is adjusted so that such an explosion will occur as the gas is turned off is very likely to flash back when operated at the rates of consumption used for simmering purposes.

The volume of air required to burn a cubic foot of gas increases as the heating value of the gas increases.   This is shown by the curves
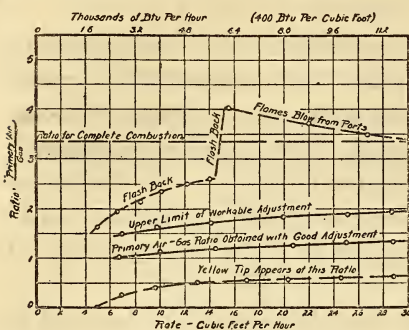
FIG. 54.—*Range of air-gas ratios over which burner No. 1 can be operated with water gas of 400 B. t. u.*
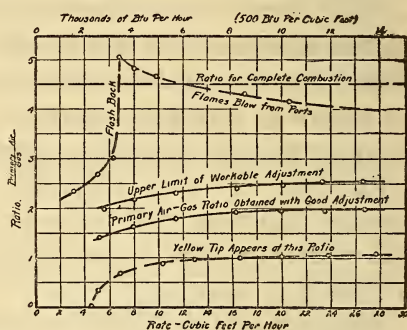
FIG. 55.—*Range of air-gas ratios over which burner No. 1 can be operated with water gas of 500 B. t. u.*

marked "Ratio for complete combustion."   A cubic foot of 400 B. t. u. water gas requires the oxygen from about 3.36 feet^3 of air for complete combustion; 500 B. t. u. water gas requires about 4.49 feet^3 of air; 600 B. t. u. water gas about 5.47 feet^3 of air, and 525 B. t. u. coal gas requires about 4.61 feet^3 of air.
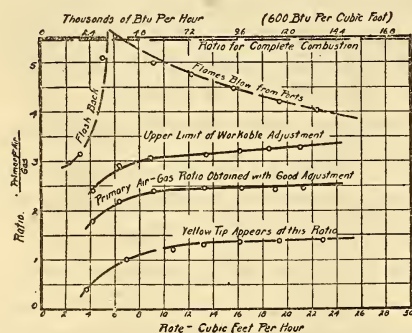
FIG. 56.—*Range of air-gas ratios over which burner No. 1 can be operated with water gas of 600 B. t. u.*
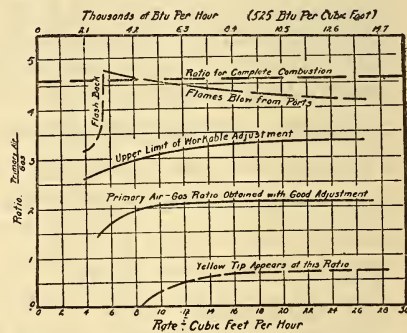
FIG. 57.—*Range of air-gas ratios over which burner No. 1 can be operated with coal gas of 525 B. t. u.*

The burner must be supplied with heat units at the same rate with gases of different heating values to maintain the same service.   The comparison of the operation of a burner with gases of different heating value has, therefore, been made when the burner consumed the same number of heat units per hour with each gas.   In making this comparison it must be remembered that the volume

of gas required to maintain a constant rate of heat units decreases as the heating value of the gas increases, and that the ratio of air to gas required to burn the gas increases as the heating value increases. To compare the operation of a burner with different gases, then, the mixture of the primary air and gas in the burner must be stated in the same terms for each gas. The B. t. u. content of a cubic foot of the air-gas mixture in the burner at the different adjustments offers the best means of comparison. The B. t. u. per cubic foot of mixture at any adjustment is determined from the gas rate and the air-gas ratio. A comparison of the air-gas ratio and B. t. u. per cubic foot of mixture obtained with Burner No. 1 with 400, 500, and 600 B. t. u. water gas and 525 B. t. u. coal gas is shown in Table 39. The air-gas ratio values are taken from Figures 54, 55, 56, and 57, which show the ratios obtained with the different gases for air-shutter adjustments which gave the same type of flame. The calculations in Table 39 of the B. t. u. per cubic foot of mixture at the various adjustments were made as follows (from Figure 54, with air shutter set for good adjustment):

B. t. u. per cubic foot.................................... 400

Rate, B. t. u. per hour.................................... 7,000

Rate, cubic feet per hour $\frac{7,000}{400}=17.5$

Air-gas ratio.................................... 1.23

Rate of air injection per hour $(17.5 \times 1.23) = 21.5$ ft.^{3}

Total rate per hour (mixture) $(17.5 + 21.5) = 39.0$ ft.^{3}

B. t. u. per cubic foot of mixture, $\frac{7,000}{39.0} = 180$.

A study of the calculations given in Table 39 shows that the B. t. u. per cubic foot of mixture at the upper limit of workable adjustment is a constant of about 140 to 145 B. t. u. for water gas of 400, 500, and 600 B. t. u./ft.^{3} This means that there would be no appreciable difference in the use of these three gases with burners adjusted in this manner. A very hard flame is obtained in each case.

The range of workable adjustments of a burner with coal gas is greater than with water gas. It is known that the same care does not have to be exercised when adjusting burners for coal gas as with water gas because the trouble from flash back is not so great. The calculations of the B. t. u. per cubic foot of mixture at the upper workable limit show that 525 B. t. u. coal gas can be satisfactorily burned if the air shutter is adjusted so that the B. t. u. per cubic foot of mixture is as low as about 120. It is interesting to note that when the air shutter was set for the good

adjustment approximately the same B. t. u. per cubic foot of mixture was obtained with these four gases. The average is between 170 and 175 B. t. u./ft.³ of mixture. At the adjustment where the yellow tip appears 400, 500, and 600 B. t. u. water gas gave about 250 to 260 B. t. u./ft.³ of mixture, while 525 B. t. u. coal gas showed a B. t. u. per cubic foot of mixture of 310 to 330. It should be expected, therefore, that fewer complaints of poor service would be experienced with burners consuming coal gas than with those burning water gas because the yellow flame occurs at a higher B. t. u. per cubic foot of mixture and the upper workable limit at a lower B. t. u. per cubic foot of mixture than with water gas.

TABLE 39.—A Comparison of Air-Gas Ratio and B. t. u. per Cubic Foot of Mixture Obtained with Burner No. 1 and 400, 500, and 600 B. t. u. Water Gas and 525 B. t. u. Coal Gas (Values Taken from Figs. 54, 55, 56, and 57).

RATE, 7,000 B. T. U./HR.

Heating value (B. t. u. per cubic foot).	Ratio of air to gas required for complete combustion.	Gas rate.	Very hard flame.		Normal flame.		Very soft flame.	
			Upper workable limit of primary air to gas.		Good adjustment of primary air to gas.		Yellow tip appears at this condition.	
			Air-gas ratio.	B. t./u. per cubic foot of mixture.	Air-gas ratio.	B. t. u./per cubic foot of mixture.	Air-gas ratio.	B. t. u. per cubic foot of mixture.
400	3.36	Ft.³/hr. 17.5	1.80	143	1.23	180	0.55	258
500	4.49	14.0	2.37	148	1.85	176	.97	254
600	5.47	11.7	3.13	145	2.46	173	1.30	261
525	4.61	13.3	3.25	124	2.11	169	.58	333

RATE, 9,000 B. T. U./HR.

Heating value	Ratio of air to gas	Gas rate.	Air-gas ratio.	B. t. u. per cubic foot	Air-gas ratio.	B. t. u. per cubic foot	Air-gas ratio.	B. t. u. per cubic foot
400	3.36	22.5	1.87	139	1.28	175	0.58	253
500	4.49	18.0	2.45	145	1.92	171	1.00	250
600	5.47	15.0	3.19	143	2.48	172	1.35	255
525	4.61	17.1	3.33	122	2.14	168	.69	312

RATE, 11,000 B. T. U./HR.

Heating value	Ratio of air to gas	Gas rate.	Air-gas ratio.	B. t. u. per cubic foot	Air-gas ratio.	B. t. u. per cubic foot	Air-gas ratio.	B. t. u. per cubic foot
400	3.36	27.5	1.92	137	1.35	170	0.61	248
500	4.49	22.0	2.50	143	1.95	170	1.00	246
600	5.47	18.3	3.25	141	2.48	172	1.38	252
525	4.61	20.9	3.38	120	2.14	168	.70	310

2. FLAME AND CONE HEIGHTS AT DIFFERENT BURNER ADJUSTMENTS WITH 400, 500, AND 600 B.T.U. WATER GAS.

The flame and cone heights vary with the heating value of the gas.—The curves, Figures 58, 59, and 60, show that with the same adjustment 600 B. t. u. water gas has a higher cone and flame height than 400 B. t. u. water gas. This means that water gas of the lower heating value burns more rapidly than gas of higher heating value.

The gas rate (B. t. u. per hour) affects the cone and flame height.—
Cone and flame heights taken from Figures 58, 59, and 60 for
rates of consumption of 7,000, 9,000, and 11,000 B. t. u./hr. show
clearly that as the rate is increased the cone and flame heights are
increased for any particular adjustment.

The cone and flame heights vary with the air-gas ratio.—The tests
have shown that over the range of adjustments at which a burner
can be satisfactorily operated the flame height continually de-
creases as the ratio of primary air to gas is increased from that
which produces the yellow tip to that where the flames blow from
ports. The cone height decreases in like manner until the point

FIG. 58.—*Cone and flame heights with varying air-gas ratios when burner No. 1 is oper-
ated with 400 B. t. u. water gas at rates of 7,000, 9,000, and 11,000 B. t. u. per hour.*

where the flames blow from ports is nearly reached, when the cones
begin to increase in height. This is more pronounced with water
gas of 400 B. t. u. (see Fig. 58) than with water gas of higher heating
value. (See Figs. 59 and 60.) The surface of the cone marks
the beginning of combustion, and the height of the cone therefore
depends on the ratio of the mixture, the velocity of the mixture,
and the rate of combustion of the gas for the different mixtures.
When the air-gas ratio is increased from a low value the increase
in the velocity of combustion is at first greater than the increase of
the velocity of the mixture through the ports, and the height of
the cone, which is formed by gas which has not yet begun to

FIG. 59.—*Cone and flame heights with varying air-gas ratios when burner No. 1 is operated with 500 B. t. u. water gas at rates of 7,000, 9,000, and 11,000 B. t. u. per hour.*
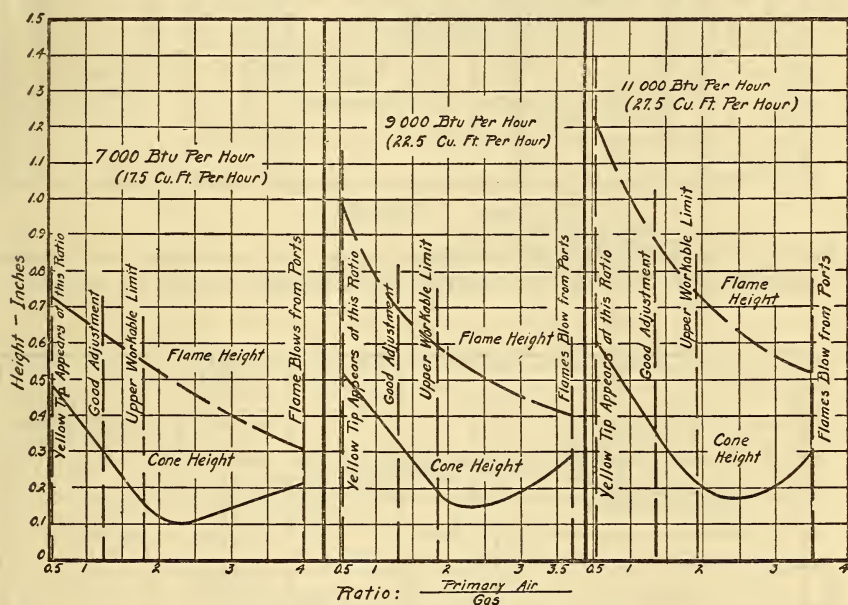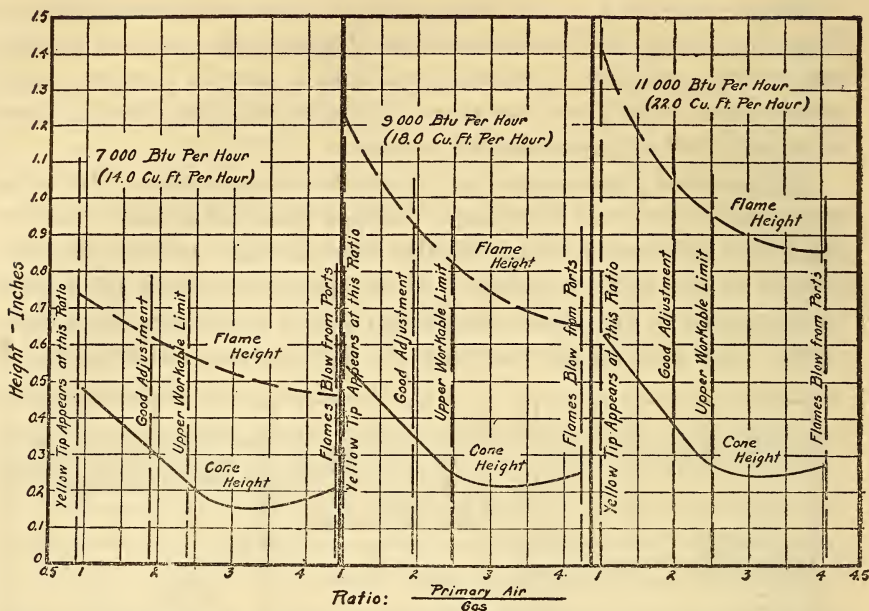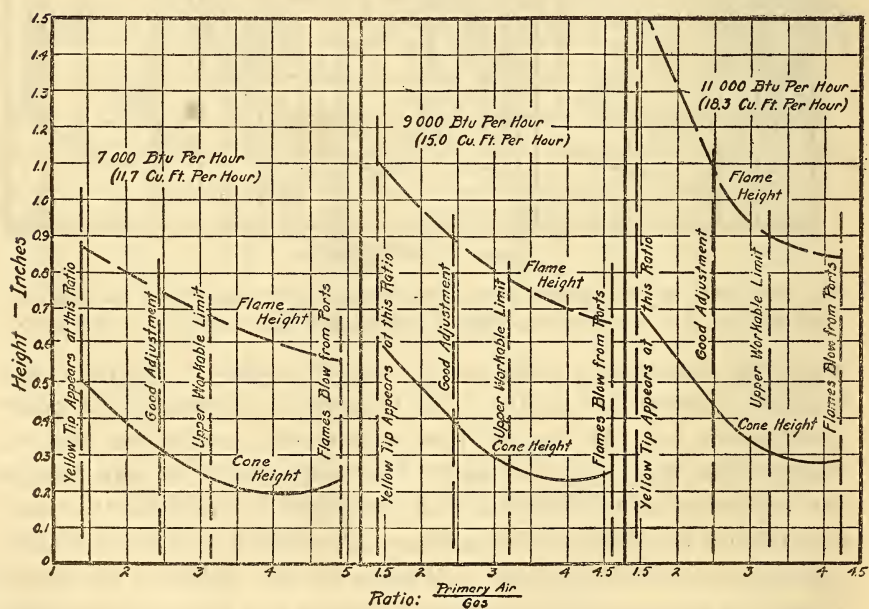

FIG. 60.—*Cone and flame heights with varying air-gas ratios when burner No. 1 is operated with 600 B. t. u. water gas at rates of 7,000, 9,000, and 11,000 B. t. u. per hour.*

burn, is decreased.   But as the primary air approaches the amount
required to completely burn the gas the velocity of combustion in-
creases less rapidly, while the increase of the velocity of the mixture
through the ports increases with the same rapidity.   When this
increase exceeds the increase of rate of combustion the cone will
lengthen, as is shown by the cone-height curves in the various
figures.   It will be noted from Figures 58, 59, and 60 that when
the cone height increases with an increase of air-gas ratio this
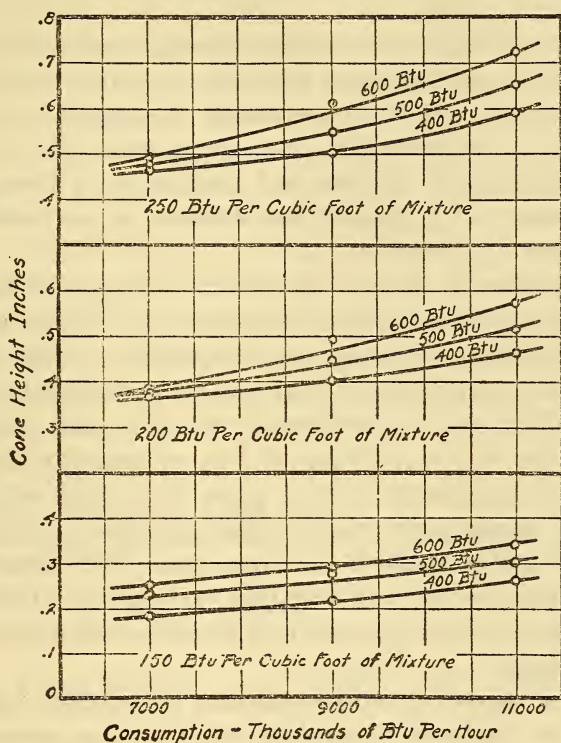
FIG. 61.—*Comparison of cone heights with 400, 500, and
600 B. t. u. water gas at 250 B. t. u. per cubic foot of
mixture within the burner (soft flame, yellow tip), 200
B. t. u. per cubic foot of mixture (medium flame), and
150 B. t. u. per cubic foot of mixture (hard flame).*

Values taken from Figs. 58, 59, and 60.

ratio is beyond the limit of upper workable adjustment where
burners will give satisfactory service.
    Cone heights taken from Figures 58, 59, and 60 have been
plotted in Figure 61 for rates of consumption of 7,000, 9,000, and
11,000 B. t. u./hr. and for three types of flames.   Figure 61 sum-
marizes the data given in the other figures and shows clearly the
effect of heating value, gas rate, and air-gas ratio on the cone height.

VII. EFFECT OF CHANGE OF SPECIFIC GRAVITY OF GAS ON THE OPERATION OF A BURNER WHEN THE ADJUSTMENT REMAINS UNCHANGED.

The practice of mixing different kinds of gases has become quite common as a result of the increase in the development of the coke-oven processes with the production of by-product gas, the building of combination coal and water gas plants, and the necessity of supplementing the supply of natural gas with different kinds of manufactured gases.

The quantity of gas sent out from the gas works will vary greatly with the daily and seasonal demand, and since no combination method of manufacture is so flexible in operation as to supply the mixture always in the same proportion, the mixture will inevitably change in gravity and perhaps, to a lesser extent, in heating value. It is usually less difficult to control the heating value than the gravity.

One objection to the use of mixtures of gases is the difficulty of making adjustments in the appliances to secure good service when the mixtures change in composition. This question of variation of composition and gravity on the operation of burners has been discussed in considerable detail in this bureau's Technologic Paper No. 193, Design of Atmospheric Gas Burners. An attempt has been made in that paper to explain why it is more difficult to change from coal or coke-oven gas to water gas than from water gas to coal or coke-oven gas. The reader is referred to that discussion for the scientific explanation of the variation in the quantity of air injected into burners with gases of different specific gravity.

It will be shown in the calculations that follow just what the effect will be on burner operation when the gas pressure, heating value, and the burner adjustment are kept constant and the specific gravity only is changed. From data taken in these tests and reported elsewhere it has been shown that for a burner operated at the "good adjustment," the heating value per cubic foot of mixture within the burner is about 175 B. t. u. Taking this condition as the initial adjustment, the data given in Tables 40 and 41 have been calculated and are explained in more or less detail in the text that follows:

1. EFFECT OF CHANGE FROM 0.40 SPECIFIC GRAVITY COKE-OVEN GAS TO 0.65 SPECIFIC GRAVITY WATER GAS.

If a top burner is adjusted for a gas rate of 18 ft.³/hr. of *500 B. t. u. coke-oven gas of 0.40 specific gravity*, the consumption will be 9,000 B. t. u./hr. (See curve *C*, Fig. 62.) With this gas the air-gas ratio for the good adjustment is 1.85 when the mixture within the burner has a heating value of 175 B. t. u./ft.³ If the burner is now supplied with *500 B. t. u. water gas* (specific gravity 0.65) without changing the pressure or adjustment of the appliance, the gas rate will be decreased to 14.14 ft.³/hr., and the air-gas ratio will be increased to 2.41. The rate at which heat is now supplied is 7,070 B. t. u./hr. and the B. t. u. per cubic foot of mixture within the burner has been changed to 146.5. Referring to Figure 62, curve *C*, it will be seen that the new operating condition falls directly upon the line determining the upper workable limit of operation. With an initial adjustment for a lower rate per hour, the new condition would fall slightly above the upper workable limit and some difficulty from flash back might be experienced with the appliance. Also, if the initial adjustment had been made for a harder flame than that represented by 175 B. t. u./ft.³ (normal flame) there would be a much greater tendency for trouble at the new condition.

TABLE 40.—Effect of Increase in Specific Gravity of Gas (from 0.40 to 0.65) on the Operation of a Burner when Adjustment Remains Unchanged—Burner No. 1, 48 Ports, No. 40 Drill—Heating Value of Gas "500" B. t. u./ft.³—Gas Pressure 3.0 Inches of Water.

[See Fig. 62.]

Change of specific gravity of gas.			Quantity of heat supplied.	Gas rate.	Primary air-gas ratio.	B. t. u. per cubic foot of mixture.
			B. t. u./hr.	Ft.³/hr.		
A	from	0.40	7,000	14.0	1.85	175
	to	.65	5,500	11.0	2.41	146.5
B	from	.40	8,000	16.0	1.85	175
	to	.65	6,280	12.56	2.41	146.5
C	from	.40	9,000	18.0	1.85	175
	to	.65	7,070	14.14	2.41	146.5
D	from	.40	10,000	20.0	1.85	175
	to	.65	7,850	15.70	2.41	146.5
E	from	.40	11,000	22.0	1.85	175
	to	.65	8,630	17.27	2.41	146.5

FIG. 62.—*Curves showing how the air-gas ratio increases and gas rate decreases with an increase of specific gravity.*

This figure applies to the case where an initial adjustment of the burner is made for 0.4 specific gravity (coal or coke-oven gas) and a normal flame (175 B. t. u. per cubic foot of mixture within the burner), and the specific gravity is then increased by mixing the coal or coke-oven gas with water gas or straight water gas of 0.65 specific gravity. It is assumed that no readjustment of the burner is made for the change in specific gravity. Curves (A, B, C, D, E) show the variation in air-gas ratio from five different initial adjustments.

The reduction from a rate of 9,000 to 7,070 B. t. u./hr. will increase the time required to do the first stages of cooking; but as this is still far above the rate required for keeping the contents of a vessel at boiling temperature, the reduction in rate should not materially interfere with the service. It has been found from experience that when changing from a coal or coke-oven gas to water gas, or from any light gas to a heavier gas, less difficulty is experienced if the heavier gas is of higher heating value than the light gas. This experience is in harmony with the physical principles explained in this paper. Briefly stated, the reason that an increase in the heating value of the heavier gas improves service is that a condition of good adjustment seems to represent a fairly definite B. t. u. mixture for all kinds of gas, and if the heavier gas is of higher B. t. u., the total rate in B. t. u. per hour supplied to the appliance and the mixture in B. t. u. per cubic foot of mixture will remain more constant.

2. EFFECT OF CHANGE FROM 0.65 SPECIFIC GRAVITY WATER GAS TO 0.40 SPECIFIC GRAVITY COKE-OVEN GAS.

If the initial adjustment in this case is made for 9,000 B. t. u./hr. with 500 B. t. u. water gas of 0.65 specific gravity, the gas rate will be 18 ft.³/hr.; and if the air shutter is adjusted for an air-gas ratio of 1.65, the mixture will contain 175 B. t. u./ft.³, which we have stated represents the condition of an average good adjustment. A change of gas to 500 B. t. u. coke-oven gas of 0.40 specific gravity, without any change in the burner adjustment, will increase the gas rate to 22.96 ft.³/hr. (equivalent to 11,480 B. t. u./hr.), while the air-gas ratio will be decreased to 1.42 and the heating value per cubic foot of mixture is increased to 207 B. t. u. Although the air-gas ratio has been reduced and the heating value of the mixture increased we have a fairly good, although a soft, flame. The gas rate with the burner cock wide open is, of course, too large for good over-all efficiency, though the consumers will not ordinarily make a complaint about too much gas. However, unless they turn the gas partly off at the cock there will be a tendency toward waste.

The discussion in this and the preceding section shows that where the heating value of the gas or the specific gravity varies, it is necessary to consider the effect of the change on the composition of the mixture and the total B. t. u. consumption and adjust the burners accordingly.
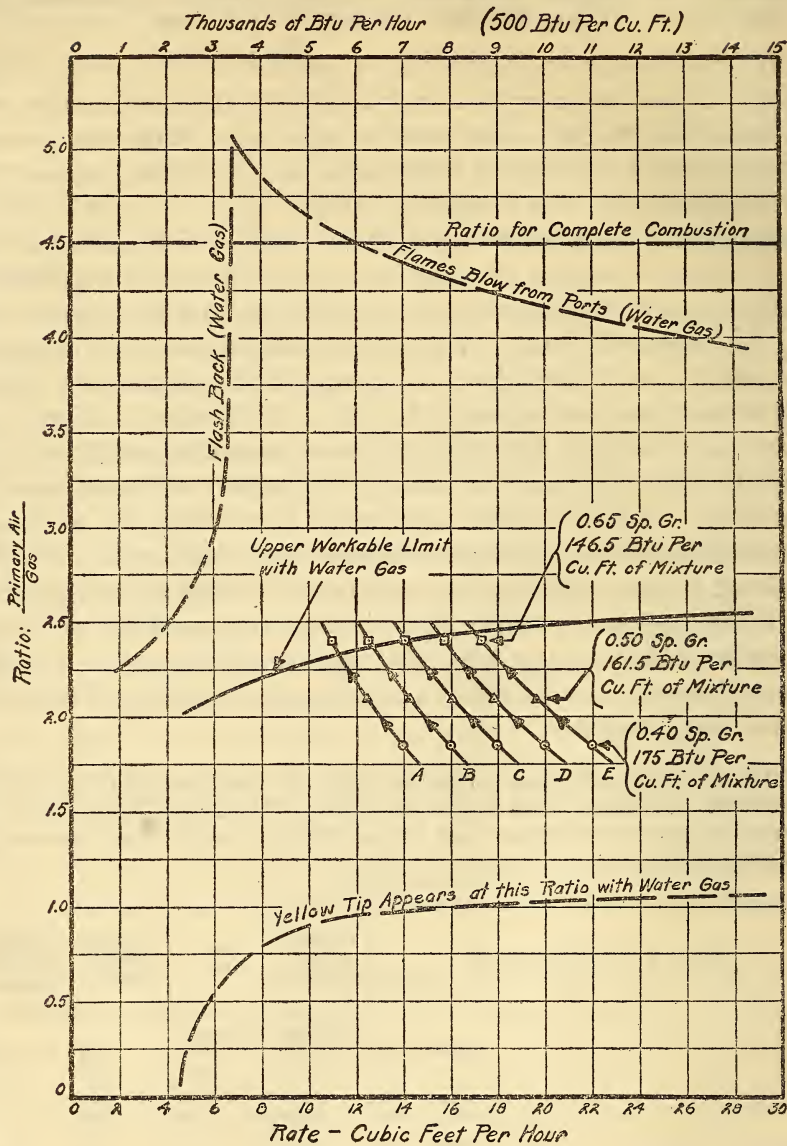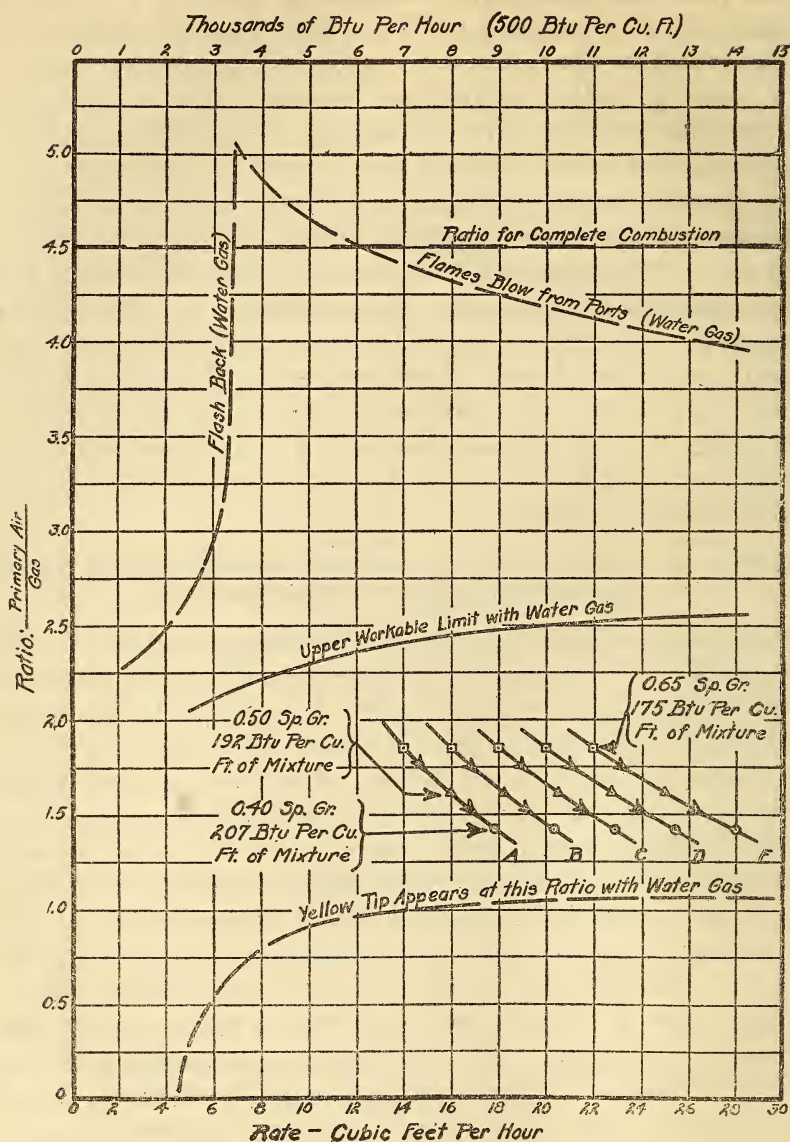
FIG. 63.—*Curves showing how the air-gas ratio decreases and gas rate increases with
a decrease of specific gravity.*

This figure applies to the case where an initial adjustment of the burner is made for 0.65 specific
gravity (water gas) and a normal flame (175 B. t. u. per cubic foot of mixture within the burner),
and the specific gravity is then decreased by mixing the water gas with coal or coke-oven gas, or
straight coal or coke-oven gas, of 0.40 specific gravity. It is assumed that no readjustment of the
burner is made for the change in specific gravity. Curves (A, B, C, D, E) show the variation in
air-gas ratio from five different initial adjustments.

TABLE 41.—Effect of Decrease of Specific Gravity of Gas (from 0.65 to 0.40) on the Operation of a Burner when Adjustment Remains Unchanged—Burner No. 1, 48 Ports, No. 40 Drill—Heating Value of Gas "500" B. t. u./ft.^{3}—Gas Pressure 3.0 Inches of Water.

[See Fig. 63.]

Change of specific gravity of gas.			Quantity of heat supplied.	Gas rate.	Primary air-gas ratio.	B. t. u. per cubic foot of mixture.
			B. t. u./hr.	Ft.^{3}/hr.		
A	from	0.65	7,000	14.0	1.85	175
	to	.40	8,930	17.85	1.42	207
B	from	.65	8,000	16.0	1.85	175
	to	.40	10,200	20.4	1.42	207
C	from	.65	9,000	18.0	1.85	175
	to	.40	11,480	22.96	1.42	207
D	from	.65	10,000	20.0	1.85	175
	to	.40	12,750	25.5	1.42	207
E	from	.65	11,000	22.0	1.85	175
	to	.40	14,020	28.04	1.42	207

3. SUGGESTED ADJUSTMENT OF GAS RANGE BURNERS IN LOCALITIES WHERE THE SPECIFIC GRAVITY OF THE GAS VARIES.

Provided satisfactory and uniform pressure conditions can be maintained, it should be possible by a correct adjustment to maintain reasonably good service with most domestic appliances even with considerable variation in the gravity. The burners must be adjusted for an average condition which will make them operate under all conditions within the three limitations prescribed for good service. These limitations are:

(1) The adjustment must be such that in changing to the heavier gas the rate in B. t. u. per hour will not be less than a certain minimum which experience has shown is necessary for good service.

(2) The adjustment must be such that when the burners are operated with the heavier gas the air injection is not too great to cause the burners to flash back when operated at low rates of consumption.

(3) The adjustment must be such that when the burners are operated with the light gas, which results in increased gas rate and reduced air injection, the flames will not be yellow, odors will not be produced, nor the utensils or mantles blackened.

If the burners are adjusted when the composition of the gas represents equal proportions of the two gases of widely different specific gravity, within the limits found in ordinary practice, no serious difficulty should be experienced in operating the appliances with either the high or low specific gravity gas, since the effect of

changing to one or the other will not change the rate in B. t. u. per hour or the flame characteristics sufficiently to cause poor service or considerable loss in efficiency.

If the gas supply is composed mostly of the heavier gas at the time the burner adjustments are made, the best average adjustment is secured if the burners are adjusted for a gas rate slightly below the normal rate and the air shutters are set so that the flame is a little harder than a normal flame. If, on the other hand, the gas supply is composed mostly of the lighter gas at the time the burner adjustments are made, the best average adjustment is obtained by regulating the gas rate to slightly above a normal rate and by setting the air-shutter position to produce flames a little softer than a normal flame.

In addition to the methods suggested by which to make a good average adjustment, other methods may be found practicable. Some change in gas pressure or heating value to compensate for changes in specific gravity might be feasible so as to maintain the required amount of heat at the appliance and yet secure a satisfactory flame.

VIII. EFFICIENCY OF GASES OF DIFFERENT HEATING VALUE WITH A CHANGE OF DISTANCE OF UTENSIL FROM BURNER AND CARBON MONOXIDE IN THE PRODUCTS OF COMBUSTION AT DIFFERENT POSITIONS.

The efficiency of a burner, as well as the amount of carbon monoxide produced, varies with the distance of the utensil from the burner, the rate of gas consumption, and the type of flame. As has been described in a previous section of this report, the size and appearance of the flame depends upon two things—the rate of gas consumption and the primary air-gas ratio. For a constant rate of consumption the appearance of the flame depends upon the amount of primary air injected into the burner which determines the heating value per cubic foot of mixture. When the heating value per cubic foot of mixture is 250 B. t. u. the flame is very soft, while for 150 B. t. u./ft.^{3} of mixture the flame is very hard.

If the B. t. u. per cubic foot of mixture is kept constant and the gas rate is varied over the ususal range of adjustment, the air-gas ratio will remain constant and the flame will possess the same degree of "hardness" or "softness," depending on the initial adjustment. The only difference caused by a change in the B. t. u. rate is in the flame volume.

This condition is analogous to turning the gas cock in actual use. If a burner is set for a medium flame (about 200 B. t. u./ft.³ of mixture) with the gas cock wide open and the cock is then partly turned off, the gas rate will be reduced, but the air-gas ratio will remain practically the same, the B. t. u. per cubic foot of mixture will remain practically unchanged, and, therefore, the type of flame will be about the same, while the flame volume will be less. The efficiency will not be the same in both cases, as the degree of flame contact will differ.

What has been said previously is illustrated in the following curves, Figures 64 to 67, inclusive, which were obtained by operating tests of two burners, burner No. 1 and burner No. 3: Each burner was tested with water gas of both 500 and 600 B. t. u./ft.³ The curves were obtained by varying the gas rate and the distance of the utensil from the burner when the B. t. u. per cubic foot of mixture was a constant. Three different adjustments were made for each heating value of gas, namely, 150, 200, and 250 B. t. u./ft.³ of mixture. The efficiency tests reported in this section were made when the utensil was suspended from an adjustable support. All the previous efficiency tests were made on stoves with grid tops, and it will be observed that slightly higher values were secured on the stoves. The explanation for this difference in the results may be that with the use of the grid there was a greater restriction to the escape of the products of combustion, which in turn reduced the supply of secondary air, lengthened the flame, and resulted in better flame contact.

1. TESTS OF BURNER NO. 1 WITH 500 AND 600 B. T. U. WATER GAS.

The curves, Figures 64 and 65, were obtained by operating the burner with 500 and 600 B. t. u. water gas. The time and efficiency curves, Figure 64A, with 500 B. t. u. gas, were made at rates of 7,000, 9,000, and 11,000 B. t. u./hr. at four different positions, while the adjustment of the burner was kept constant at 150 B. t. u./ft.³ of mixture. In a similar manner the curves in Figure 64, *B* and *C*, were made by changing the B. t. u. per cubic foot of mixture. Tests were made with 600 B. t. u. gas in similar manner and the results are shown in Figure 65.

The position of the burner relative to the utensil has a marked effect on the efficiency. It will be noted in referring to the accompanying figures that as the distance between utensil and burner is increased there is a decrease in efficiency. This is due to a decrease

FIG. 64.—*Curves showing efficiency obtained with change of distance of utensil from burner.*

Tests made with burner No. 1, 500 B. t. u. water gas and three types of flame. Chart A obtained with 150 B. t. u. per cubic foot of mixture within the burner (hard flame); Chart B, 200 B. t. u. per cubic foot of mixture (medium flame); Chart C, 250 B. t. u. per cubic foot of mixture (soft flame—yellow tip).

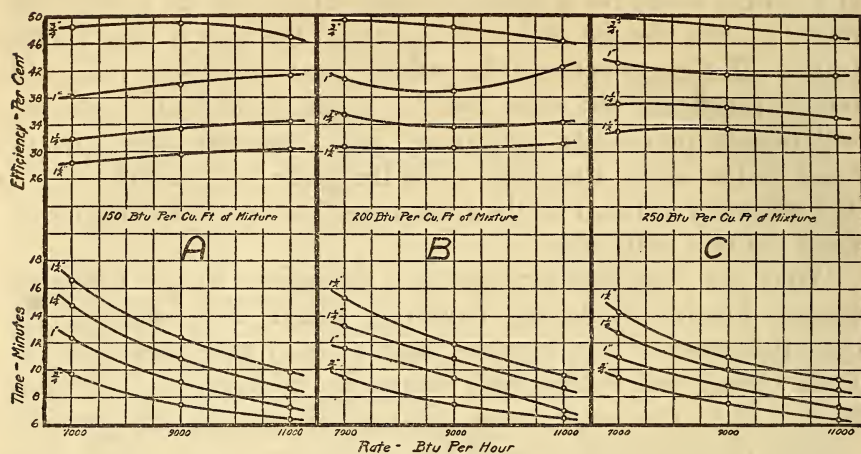FIG. 65.—*Curves showing efficiency obtained with change of distance of utensil from burner.*

Tests made with burner No. 1, 600 B. t. u. water gas and three types of flame. Chart A obtained with 150 B. t. u. per cubic foot of mixture within the burner (hard flame); Chart B, 200 B. t. u. per cubic foot of mixture (medium flame); Chart C, 250 B. t. u. per cubic foot of mixture (soft flame—yellow tip).
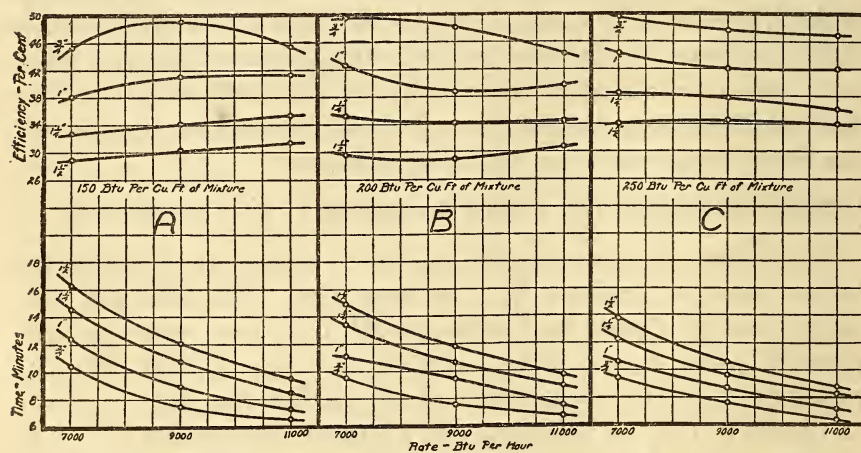
in the amount of flame contact. The decrease in efficiency caused by moving the utensil from the ¾-inch to the 1½-inch position amounts to about 15 per cent irrespective of the gas rate.

At the ¾-inch position the higher gas rate gives a lower efficiency. The efficiency tends to increase with the amount of flame contact until the flame begins to extend up the side of the utensil. When this occurs a large part of the available heat in the flame is lost by radiation and convection and the efficiency decreases. This is what happens when the rate is 11,000 B. t. u./hr. for the ¾-inch position.

The efficiency varies only slightly with a change of gas rate for the usual distance of utensil from burner. When the gas rate is increased there is an accompanying increase in the flame volume and, as shown by the curves, the efficiency is slightly greater for 11,000 B. t. u./hr. than for the 7,000 B. t. u./hr. rate only with the hard flame.

The efficiency will vary with the type of flame. There is a difference in the flame volume for the adjustments of 150, 200, and 250 B. t. u./ft.^{3} of mixture. It is, therefore, evident that when the utensil is in any one position the flame contact for these three adjustments will not be the same and, therefore, the efficiency will differ. Since the efficiency depends almost entirely on good flame contact there is some one position for each type of flame that will give a maximum heat absorption. Whether the type of flame corresponding to 150, 200, or 250 B. t. u./ft.^{3} of mixture for any particular gas rate gives the best efficiency depends on the distance between the burner and the utensil.

All the curves are similar for the 500 and 600 B. t. u. water gas for the same burner. It will be noted that the curves for 600 B. t. u. water gas are almost identical with those obtained when using 500 B. t. u. water gas, which shows that the heating value of the gas makes no difference in the efficiency of a burner, provided that the comparison is made when the B. t. u. per cubic foot of mixture is constant.

2. TESTS OF THE BURNER NO. 3 WITH 500 AND 600 B. T. U. WATER GAS.

The curves shown in Figures 66 and 67 for this burner were determined in the same way as was done in the case of Burner No. 1. The same conclusions can be drawn in connection with this burner as were pointed out with reference to the other. It will be noted that the efficiencies obtained with this burner are consistently higher

FIG. 66.—*Curves showing efficiency obtained with change of distance of utensil from burner.*

Tests made with burner No. 3, 500 B. t. u. water gas and three types of flame. Chart A obtained with 150 B. t. u. per cubic foot of mixture within the burner (hard flame); Chart B, 200 B. t. u. per cubic foot of mixture (medium flame); Chart C, 250 B. t. u. per cubic foot of mixture (soft flame—yellow tip).

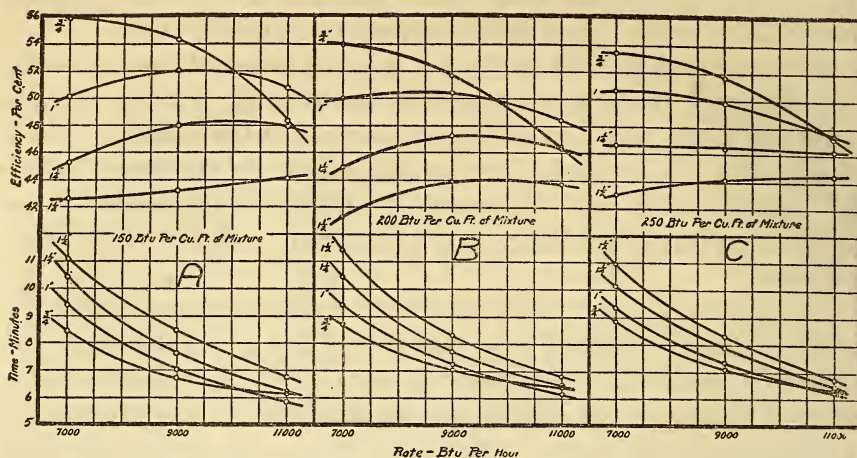FIG. 67.—*Curves showing efficiency obtained with change of distance of utensil from burner.*

Tests made with burner No. 3, 600 B. t. u. water gas and three types of flame. Chart A obtained with 150 B. t. u. per cubic foot of mixture within the burner (hard flame); Chart B, 200 B. t. u. per cubic foot of mixture (medium flame); Chart C, 250 B. t. u. per cubic foot of mixture (soft flame—yellow tip).
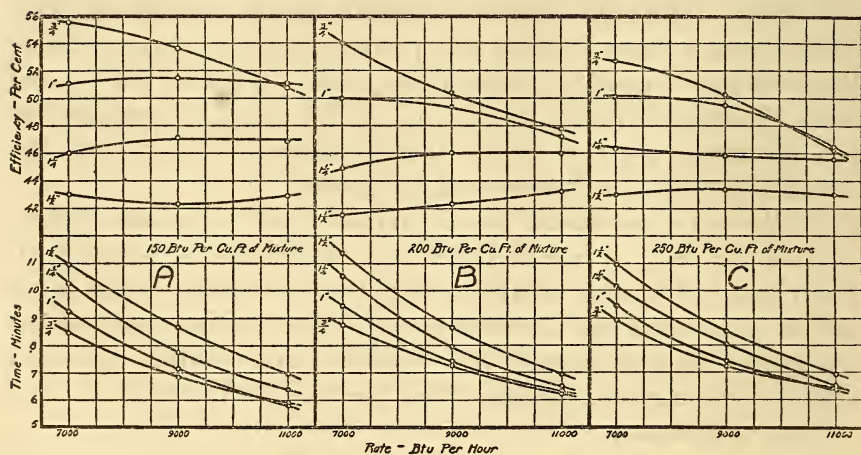
than those obtained for similar adjustments with Burner No. 1. This is due in a large measure to the tendency of the flame to incline toward the center and thus give a concentration of heat at this point. This type of burner is such that there is insufficient aeration of the flame, which results in an increase in the flame volume, and therefore better flame contact. The effect of flame volume is markedly shown by referring to Figure 67C, which gives results on a burner adjusted to a soft flame (250 B.t.u./ft.^{3} of mixture). When the utensil is placed three-fourths inch from the burner with a gas rate of 11,000 B.t.u./hr. the flame volume is so great that the corresponding heat lost by radiation and convection lowers the efficiency to that obtained at the 1-inch position.

The minimum distance between utensil and burner is determined by the production of carbon monoxide. It has been pointed out in the foregoing that for all adjustments the closer the utensil is placed to the burner the higher the efficiency obtained. However, when a utensil is placed so close to a burner that there is cone contact, carbon monoxide is produced. As this gas, even when present in the room atmosphere in small quantities, is detrimental to health, it is advisable to place the utensil at a distance from the burner that will give the highest obtainable efficiency without the formation of carbon monoxide.

Tables 42, 43, 44, and 45 were prepared from analyses of the products of combustion from Burner No. 1 and Burner No. 3 and also from careful observations of the appearance of the flame for the different conditions of test. Tables 42 and 43 for Burner No. 1 show that the position chosen should be about 1 inch, while Tables 44 and 45 for Burner No. 3 show that the utensil should not be placed closer than about 1½ inches.

TABLE 42.—Carbon Monoxide in Products of Combustion from "500" B. t. u. Water Gas When Burner is at Different Distances from Utensil—Burner No. 1, 48 Ports, No. 40 Drill.

Quantity of heat supplied (B.t.u./hr).	Distance of utensil from burner.	150 B.t.u./ft.^{3} of mixture (hard flame).		200 B.t.u./ft.^{3} of mixture (medium flame).		250 B.t.u./ft.^{3} of mixture (soft flame, yellow tip).	
		CO produced.	Remarks.	CO produced.	Remarks.	CO produced.	Remarks.
	Inches.	Ft.^{3}/hr.		Ft.^{3}/hr.		Ft.^{3}/hr.	
7,000 (14 ft.^{3}).	¾	0	General flame contact.	0.05	Slight cone contact. General flame contact.	0.17	General cone contact.
	1	0	Slight flame contact.	0	General flame contact.	Trace.	Some cones extend to utensil.
	1¼	0	No flame contact..	0	Slight flame contact.	0	General flame contact.
	1½	0	.....do.............	0	No flame contact..	0	Slight flame contact in center.
9,000 (18 ft.^{3}).	¾	0.07	Some cones extend to utensil. Flame extends up side of utensil.	.11	Cones extend to utensil. Flame extends up side of utensil.	.17	All cones extend to utensil. Flame extends up side of utensil.
	1	0	General flame contact.	0	General flame contact.	Trace.	Slight cone contact.
	1¼	0	Slight flame contact.	0	Flame contact.....	0	Flame contact.
	1½	0	A little flame contact at center.	0	Slight flame contact.	0	Slight flame contact.
11,000 (22 ft.^{3}).	¾	.29	About one-half cones extend to utensil.	.25	Most of cones extend to utensil. Flame extends up side of utensil.	.27	All cones extend to utensil. Flame extends up side of utensil.
	1	0	General flame contact.	Trace.	Slight cone contact. General flame contact.	Trace.	Slight cone contact. Flame extends up side of utensil.
	1¼	0	Flame contact.....	0	General flame contact.	0	General flame contact.
	1½	0	A little flame contact.	0	Flame contact.....	0	Flame contact.

TABLE 43.—Carbon Monoxide in Products of Combustion from "600" B. t. u. Water Gas When Burner is at Different Distances from Utensil—Burner No. 1, 48 Ports, No. 40 Drill.

Quantity of heat supplied (B.t.u./hr).	Dis-tance of utensil from burn-er.	150 B.t.u./ft.³ of mixture (hard flame).		200 B.t.u./ft.³ of mixture (medium flame).		250 B.t.u./ft.³ of mixture (soft flame, yellow tip).	
		CO pro-duced.	Remarks.	CO pro-duced.	Remarks.	CO pro-duced.	Remarks.
	Inches.	Ft.³/hr.		Ft.³/hr.		Ft.³/hr.	
7,000 (11.7 ft.³).	¾	0	Flame contact.....	0.05	A few cones ex-tend to utensil. Flame contact.	0.20	Cones extend to utensil. General flame contact.
	1	0	Slight flame con-tact.	Trace.	Slight cone con-tact. Flame con-tact.	Trace.	Slight cone con-tact. Flame con-tact.
	1¼	0	No flame contact..	0	Slight flame con-tact.	0	General flame con-tact.
	1½	0	.....do............	0	No flame contact..	0	Flame contact at center.
9,000 (15 ft.³).	¾	0.15	Few cones extend to utensil.	.08	Some cones ex-tend to utensil.	.20	Cones extend to utensil. Flame extends up side of utensil.
	1	0	Flame contact.....	0	General flame contact.	Trace.	Slight cone con-tact. Flame ex-tends up side of utensil.
	1¼	0	Slight flame con-tact.	0	Slight flame con-tact.	0	General flame con-tact.
	1½	0	No flame contact..	0	No flame contact..	0	Slight flame con-tact.
11,000 (18.3 ft.³).	¾	.22	Most of cones ex-tend to utensil.	.24	General cone con-tact.	.18	General cone con-tact. Flame ex-tends up side of utensil.
	1	Trace.	General flame contact. Slight cone contact.	Trace.	Slight cone con-tact.	Trace.	Slight cone con-tact. Flame ex-tends up side of utensil.
	1¼	0	Slight flame con-tact.	0	General flame contact.	0	Flame extends up side of utensil.
	1½	0	Flame contact at center.	0	Flame contact.....	0	General flame con-tact.

TABLE 44.—Carbon Monoxide in Products of Combustion from "500" B. t. u. Water Gas When Burner is at Different Distances from Utensil—Burner No. 3, 45 Ports, No. 38 Drill.

Quantity of heat supplied. (B.t.u./hr.)	Distance of utensil from burner.	150 B.t.u./ft.³ of mixture (hard flame).		200 B.t.u./ft.³ of mixture (medium flame).		250 B.t.u./ft.³ of mixture (soft flame, yellow tip).	
		CO produced.	Remarks.	CO produced.	Remarks.	CO produced.	Remarks.
	Inches.	Ft.³/hr.		Ft.³/hr.		Ft.³/hr.	
7,000 (14 ft.³).	¾	0.18	Cone contact at outer ports.	0.20	Cone contact at outer ports.	0.19	General cone contact.
	1	Trace.	Slight cone contact.	Trace.	Slight cone contact. Flame contact.	.05	A few cones extend to utensil.
	1¼	0	No flame contact...	0	Slight flame contact.	0	Slight flame contact.
	1½	0	.....do.............	0	No flame contact...	0	No flame contact.
9,000 (18 ft.³).	¾	.20	Cone contact except at the central ports.	.23	Cone contact except at central ports. Flame extends up side of utensil.	.28	General cone contact. Flame extends up side of utensil.
	1	.12	Cone contact at outer ports.	.11	Cone contact at outer ports.	.12	Cone contact at outer ports.
	1¼	Trace.	A few cones extend to utensil.	Trace.	A few cones extend to utensil.	Trace.	A few cones extend to utensil.
	1½	0	Slight flame contact.	0	Flame contact.....	0	Flame contact.
11,000 (22 ft.³).	¾	.22	General cone contact. Flame extends up side of utensil.	.20	General cone contact. Flame extends up side of utensil.	.23	General cone contact. Flame extends up side of utensil.
	1	.19	Outer cones extend to utensil. Flame extends up side of utensil.	.17	Outer cones touch utensil. Flame extends up side of utensil.	.15	Outer cones touch utensil. Flame extends up side of utensil.
	1¼	.09	A few cones extend to utensil. Flame extends up side of utensil.	.10	A few cones extend to utensil. Flame extends up side of utensil.	.08	A few cones extend to utensil. Flame extends up side of utensil.
	1½	0	General flame con-contact.	Trace.	Slight cone contact. General flame contact.	Trace.	Slight cone contact. General flame contact.

TABLE 45.—Carbon Monoxide in Products of Combustion from "600" B. t. u. Water Gas When Burner is at Different Distances from Utensil—Burner No. 3, 45 Ports, No. 38 Drill.

Quantity of heat supplied (B.t.u./hr.).	Distance of utensil from burner.	150 B.t.u./ft.³ of mixture (hard flame).		200 B.t.u./ft.³ of mixture (medium flame).		250 B.t.u./ft.³ of mixture (soft flame, yellow tip).	
		CO produced.	Remarks.	CO produced.	Remarks.	CO produced.	Remarks.
	Inches.	Ft.³/hr.		Ft.³/hr.		Ft.³/hr.	
7,000 (11.7 ft.³).	¾	0.15	Cone contact at outer ports.	0.16	Cone contact at outer ports. Flame extends up side of utensil.	0.19	General cone contact. Flame extends up side of utensil.
	1	Trace.	A few outer cones extend to utensil.	Trace.	A few cones extend to utensil.	Trace.	Slight cone contact.
	1¼	0	No flame contact...	0	Slight flame contact.	0	Slight flame contact.
	1½	0	.....do.............	0	No flame contact...	0	No flame contact.
9,000 (15 ft.³).	¾	.19	Cone contact. Flame contact.	.21	Cone contact. Flame extends up side of utensil.	.24	General cone contact. Flame extends up side of utensil.
	1	.10	Slight cone contact.	.12	Cone contact at outer ports. Flame extends up side of utensil.	.13	Cone contact. Flame extends up side of utensil.
	1¼	Trace.	.....do.............	Trace.	Slight cone contact.	Trace.	Slight cone contact.
	1½	0	No flame contact...	0	Slight flame contact.	0	Slight flame contact.
11,000 (18.3 ft.³).	¾	.25	Cones extend to utensil. Flame extends up side of utensil.	.24	Cones extend to utensil. Flame extends up side of utensil.	.19	General cone contact. Flame extends up side of utensil.
	1	.19	Cones extend to utensil.	.15	Cone contact.......	.14	Cone contact. Flame extends up side of utensil.
	1¼	.07	A few cones extend to utensil.	.05	Slight cone contact.	.06	Slight cone contact. Flame extends up side of utensil.
	1½	0	Flame contact.....	0	General flame contact.	0	General flame contact.

IX. EFFECT OF CAREFUL OPERATION OF GAS BURNERS ON GAS CONSUMPTION.

Many cooking processes require the heating of the water in the utensil up to boiling and the maintenance of the boiling temperature (212° F.) thereafter until the food is completely cooked. Some people forget or do not know that water can not be heated to a temperature higher than 212° F. at atmospheric pressure and that violent boiling does not accelerate the speed of cooking. It only evaporates water needlessly, wastes gas, and causes the consumer to complain of high gas bills.

Some idea of the difference between careless operation and careful operation of an appliance can be gained from the tests reported in Table 46.

TABLE 46.—Tests of Evaporation of Water with "City Gas" of 502 B. t. u.

Test No.	Gas rate.	Quantity of heat supplied.	Quantity of water used.	Time required for complete evaporation.	Remarks.
	Ft.³/hr.	B. t. u./hr.	Quarts.	Hours.	
1.............................	2.05	1,030	2	9.15	Lid on, gentle boiling.
2.............................	10.62	5,330	2	1.49	Lid off, gentle boiling.
3.............................	18.42	9,250	2	1.13	Lid on, violent boiling.
4.............................	18.50	9,290	2	1.10	Lid off, violent boiling.

NOTE.—To make the lid-on tests a piece of plate glass was placed over the utensil in order to observe the degree of boiling. A small opening corresponding to a loose-fitting lid allowed the steam to escape. In tests Nos. 1 and 2 the water was in a state of gentle boiling, whereas in Nos. 3 and 4 the water was violently agitated by the boiling.

The following important conclusions may be drawn from these evaporation tests:

1. With a lid on the utensil, violent boiling (gas on full) consumes about nine times more gas than is necessary to maintain gentle boiling.

2. For gentle boiling about five times as much gas is used with the lid off as would be required if a lid were on the utensil.

3. When violently boiled the water evaporates at about the same rate with the lid on as with the lid off.

4. Gentle boiling evaporates water about six times as fast with the lid off as compared with the lid on.

X. SUMMARY.

In connection with an investigation conducted by the Public Service Commission of Maryland to determine the most economic heating-value standard for manufactured gas in the city of Baltimore, the Bureau of Standards carried on an extensive series of laboratory tests of gases of different heating value and composition.

In this report of the laboratory tests are discussed three of the many important factors that must be considered in determining the relative service value of different gases. They are (1) what is the relative utilization efficiency of gases of different heating value when each gas is tested under the most practical conditions? (2) to what extent can the present appliances be adapted to give good and efficient service with gases of different heating value and composition? (3) what adjustment in appliances is necessary to give the consumers good and efficient service when different kinds of gases are mixed and the composition, heating value, and the specific gravity change as a result of daily and seasonal variations in the send out?

1. RELATIVE UTILIZATION EFFICIENCY OF GASES OF DIFFERENT HEATING VALUE.

Since it is desirable to compare the relative efficiency of gases of different heating value under conditions most favorable to each gas, it is necessary to consider the effect of air-shutter adjustment, distance of utensil from the burner, and the gas rate.

The efficiency of a burner varies with the type of flame. The size and appearance of a flame depend upon the composition of the gas, the gas rate, the heating value, and the primary air-gas ratio. The heating value and ratio of primary air to gas determine the B. t. u. per cubic foot of the mixture within the burner. An adjustment that gives a mixture of gas and air within the burner with a heating value of 250 B. t. u./ft.³ gives a very soft flame, while a mixture of 150 B. t. u./ft.³ gives a very hard flame. The good adjustment for all the gases showed that the mixture had an average heating value of about 175 B. t. u./ft.³ If the gas rate is varied over the usual range of adjustment by a change in the pressure at the gas orifice, the flame volume will vary, but the B. t. u. per cubic foot of mixture remains practically constant and the flame will possess almost the same degree of "hardness" or "softness" (depending on the initial adjustment).

With a hard flame the efficiency tends to increase slightly with an increase in gas rate for any one distance of the utensil from burner. This is true, in general, except when the utensil is placed three-fourths inch or less from the burner. There is a difference in flame volume according to whether the adjustment is made for a soft, medium, or hard flame. It is evident, therefore, that when the utensil is in any one position the flame contact for these three adjustments will not be the same and, therefore, the efficiency will differ.

The distance between the burner and the utensil has a marked effect on the efficiency. The efficiency varies inversely as the distance between the utensil and burner and tends to increase with the amount of flame contact until the flame extends up the side of the utensil. When this occurs a large part of the available heat in the flame is lost by radiation and convection and the efficiency decreases.

Maximum efficiency can not be secured because of formation of carbon monoxide at close position of the utensil to burner. A distance of three-fourths inch, or less, would give the maximum efficiency; but when a utensil is placed so close to a burner that there is cone contact, carbon monoxide is produced. Since this

gas, even when present in the room atmosphere in small quantities, is detrimental to health, it is advisable to place the utensil at a distance from the burner that will give the highest efficiency without the formation of carbon monoxide. The results of these tests show that for the size of vessel used the minimum distance should be about 1 inch for Burner No. 1, while for Burner No. 3 the vessel should not be placed closer than about 1½ inches.

With burners properly located and adjusted the danger from carbon monoxide is remote with normal rates of gas consumption. The analyses show that with the ranges used, the burners of which were 1⅜ inches from the vessel, practically no carbon monoxide was produced with any of the gases tested, unless gas was burned at a rate greater than about 12,000 B. t. u./hr. Above this rate the amount of carbon monoxide produced was sufficient to cause headaches in a poorly ventilated room. The tests showed that the disk type of burner produced more carbon monoxide than the star type, when operated at the same distance (1⅜ inches) from utensil and at the same rate of consumption.

Although the production of carbon monoxide varied with the position and adjustment of burner and the rate of consumption, if the gases are compared under conditions that are considered proper for each gas, it can be said that the heating value or the kind of gas did not seem to be factors affecting the production of carbon monoxide.

After giving due consideration to the before-mentioned factors which have an influence on efficiency, we can draw the following conclusions from these laboratory tests:

(1) *Irrespective of the heating value of the gas, the efficiency (ratio of heat absorbed to heat contained in the gas burned) obtained with any one burner is very nearly constant, provided the burner is adjusted to consume the same number of B. t. u. per hour with each gas.* Thus, to heat a given quantity of water to the same temperature in the same time required 2 feet^3 of 300 B. t. u. gas to 1 foot^3 of 600 B. t. u. gas. In other words, the quantity of gas required varied inversely with the heating value of the gas.

(2) When the burners of standard size were adjusted for a gas rate of 9,000 B. t. u./hr., an efficiency of about 37 per cent was secured, and it required almost exactly 10 minutes to heat 2 quarts of water from 80° F. to boiling with each kind of gas. (See Table 33 and Fig. 50.) At a rate of 7,000 B. t. u./hr. an average efficiency of about 36 per cent was obtained with Burner No. 1 (see Table 32) and about 13 minutes were required. For a rate of 11,000

B. t. u./hr. the average efficiency was about 37.7 per cent (see Table 34) and the time required was about 8 minutes. *These results show that over the range of usual operating conditions the efficiency of heat absorption varies only slightly with a change in the rate of heat supply. It follows, therefore, that the rate of heating varies almost directly with the rate of supply of heat.*

2. EXTENT TO WHICH THE PRESENT APPLIANCES CAN BE ADAPTED TO GIVE GOOD AND EFFICIENT SERVICE WITH GASES OF DIFFERENT HEATING VALUE AND COMPOSITION.

(1) Appliances require less pressure to give good combustion with lower heating value gases. Tests of Burner No. 1 show that with 500 B. t. u. water gas a pressure of 1 inch is sufficient to give the required primary air for good adjustment, and with 600 B. t. u. water gas a pressure of about 1¼ inches is sufficient.

The best results are secured from appliances when the gas pressure is constant and the appliance is adjusted to give sufficient heat and good combustion at the average rate required for cooking. Since it is not economical to distribute gas at a very low pressure, the burners are usually adjusted for a pressure much higher than is actually required for a good operation of the appliance. In other words, the pressure that is carried in the gas mains is not determined entirely by the requirements of the appliances, but by distribution costs. Complaints of poor pressure are, therefore, often due not to insufficient pressure in the mains but to improper adjustment of the appliances.

(2) Burner No. 2 could be adjusted to 450 B. t. u. gas with a 3-inch pressure without any changes in the burner. With a gas of any lower heating value, a tighter-fitting air shutter would be required for a proper regulation of the primary air.

Burner No. 1 could be adjusted to 350 B. t. u. gas without any change in the appliance.

(3) The range of workable adjustments of a burner with coal gas is somewhat greater than with water gas. The tests show that the yellow flame occurs at a higher B. t. u. per cubic foot of mixture (lower air-gas ratio) and the upper limit of workable adjustment at a lower B. t. u. per cubic foot of mixture (higher air-gas ratio) with coal gas than with water gas.

The results on the whole show that present domestic range burners can be adjusted to give satisfactory service over a wide range in heating value, the slight differences in behavior of the different gases not being of sufficient importance to have much weight in any consideration of their relative merits for use in domestic appliances.

3. ADJUSTMENT IN APPLIANCES NECESSARY TO GIVE THE CONSUMERS GOOD AND EFFICIENT SERVICE, WHEN DIFFERENT KINDS OF GASES ARE MIXED AND THE COMPOSITION, HEATING VALUE, AND THE SPECIFIC GRAVITY CHANGE.

The development in the coke-oven processes with the production of by-product gas, the building of combination coal and water gas plants, and the necessity of supplementing natural gas with different kinds of manufactured gas has resulted in the delivery of mixed gases in many localities. The variation in heating value and specific gravity of the mixed gas may cause service troubles, unless the appliances are properly adjusted.

It is possible by a correct adjustment of appliances to maintain good service even with considerable variation in the gravity. The burners must be adjusted for an average condition which will permit them to be operated under all conditions within the three limitations prescribed for good service. These limitations are:

(1) The adjustment must be such that in changing to the heavier gas the rate in B. t. u. per hour will not be reduced below a certain minimum which experience has shown is necessary for good service.

(2) The adjustment must be such that when the burners are operated with the heavier gas, the air injection is not too great to cause the burners to flash back when operated at low rates of consumption.

(3) The adjustment must be such that when the burners are operated with the light gas, which results in increased gas rate and reduced air injection, the flames will not be yellow, odors will not be produced, nor the utensils or mantles blackened.

If a burner is adjusted when the composition of the gas represents equal proportions of two gases of widely different specific gravity, no difficulty should be experienced in operating the appliance with either the high or low specific gravity gas, since the effect of changing to one or the other will not change the rate in B. t. u. per hour nor the flame characteristics sufficiently to cause poor service or loss in efficiency.

If a burner is adjusted when the gas consists mostly of the heavier gas, the best average adjustment would be secured by regulating the gas rate slightly below the normal rate and by setting the air shutter to give a flame harder than a "normal" flame. If, on the other hand, the gas consists mostly of the lighter gas at the time the burner adjustment is made, the best

average adjustment would be obtained by regulating the gas rate to slightly above a normal rate and by setting the air shutter to produce a flame softer than a "normal" flame.

In addition to the methods suggested for making a good average adjustment, other methods may be found practicable. Some change in gas pressure or heating value to compensate for changes in specific gravity might be feasible so as to maintain the required amount of heat at the appliance and yet secure a satisfactory flame.

It is quite practicable, therefore, for appliance fitters to adjust domestic range burners so that the service will be satisfactory and there will be no appreciable loss in efficiency, even though the heating value, the specific gravity, and pressure vary over considerable limits. Certain types of gas lamps and industrial appliances which demand a rather constant B. t. u. rate per hour would not operate as satisfactorily under these conditions. In general, the less variation there is in heating value, composition, specific gravity, and gas pressure, the easier it is to adjust the appliances to the most ideal condition and the more satisfactory will be the service.

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